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SURVEILLANCE SIMULATION TESTING OF TERMINAL AND EN ROUTE MODE S--ETC(U)
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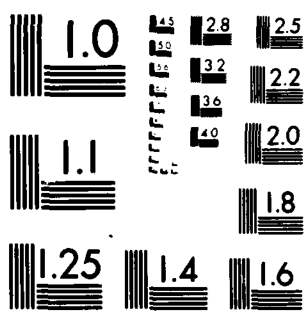

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Report No. DOT/FAA/CT-81/16

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SURVEILLANCE SIMULATION TESTING OF TERMINAL AND EN ROUTE MODE S SENSORS

ADA112250

Robert B. Frack

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INTERIM REPORT

JANUARY 1982

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16. Abstract

A test and evaluation (T&E) was conducted to determine the surveillance characteristics of the Mode S (formerly the Discrete Address Beacon System (DABS))en route and terminal sensors operating with effective receive beam widths of 2.4° and 3.4°.

The tests described herein were conducted at the FAA Technical Center for terminal and en route Mode S configurations having maximum ranges of 60 and 200 nautical miles (nmi), respectively. Surveillance loading was simulated using an aircraft reply and interference environment simulator (ARIES) to provide Mode S, Air Traffic Control Radar Beacon System (ATCRBS), or a mixture of the two types of aircraft. Surveillance characteristics were measured by determining the percent detection, blip scan ratio, Mode 3/A and C reliability, Mode S identifier (ID) reliabi[illegible] and the number of replies per report or interrogations per scan for both [illegible] of aircraft.

It was concluded that increasing the effective receive beam width had negligible impact on the surveillance characteristics of either sensor operating with simulated Mode S targets. Increasing the effective receive beam width improved the percent detection and Mode C reliability for both sensors operating with simulated ATCRBS targets.

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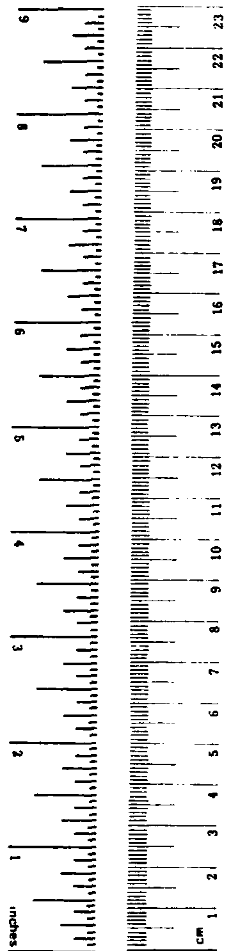
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

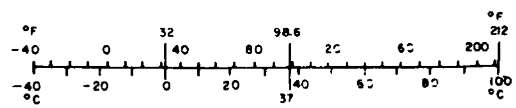


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF TABLES

INTRODUCTION

PURPOSE.

The purpose of this test and evaluation (T&E) effort was to:

1. Determine the baseline surveillance characteristics of the Mode S (formerly the Discrete Address Beacon System (DABS)) terminal and en route sensor utilizing an effective receive beam width of 2.4° with single site Mode S software release 6.3.

2. Determine the surveillance characteristics of the Mode S terminal and en route sensors using an effective receive beam width of 3.4° with multisite Mode S software release 7.2.

3. Compare the surveillance characteristics of the en route and terminal sensors for effective receive beam widths of 2.4° and 3.4°.

BACKGROUND.

The requirement for the development of Mode S was identified in the 1969 Department of Transportation Air Traffic Control Advisory Committee (ATCAC) Study. The first phase of Mode S development consisted of a feasibility study and validation of the Mode S concept. This study was conducted by the Massachusetts Institute of Technology (MIT) Lincoln Laboratory. After successfully demonstrating the feasibility of the Mode S concept, engineering requirements (ER's) were prepared by Lincoln Laboratory for the development of three single-channel Mode S sensors which could operate as a network and interface with terminal air traffic control (ATC) facilities.

Texas Instruments (TI), Incorporated, was awarded a contract to fabricate the three engineering models of the Mode S sensor. After completing factory acceptance tests, the sensors were delivered to the Federal Aviation Administration (FAA) Technical Center, Clementon, and Elwood, New Jersey, where they were installed and subjected to field acceptance tests. Upon completion of the field acceptance tests, system baseline tests were conducted on the terminal configured sensor.

The two principal objectives of the baseline tests as documented in report No. FAA-NA-79-52, "Discrete Address Beacon System (DABS) Baseline Test and Evaluation," dated April 1980, were: (1) to determine the baseline performance characteristics of the Mode S sensor employing the software and associated parameter values as delivered; and (2) to highlight those areas where changes in system parameters, due to the continual maturing of the Mode S automated traffic advisory and resolution service (ATARS) concept, would require further study and test prior to issuance of the technical data package (TDP).

It was concluded that the Mode S engineering sensor complied with or exceeded most of the requirements specified in the Mode S ER FAA-ER-240-26. It was felt that surveillance performance could be enhanced in the areas of altitude reliability and Air Traffic Control Radar Beacon System (ATCRBS) percent detection by increasing the effective receive beam width.

Additional tests were conducted by the FAA Technical Center to determine the performance of the multichannel receiver and the ATCRBS and Mode S processors. Each

of the three subsystems were tested separately and each met the requirements specified in the ER, as detailed in report FAA-RD-80-75, "Discrete Address Beacon System (DABS) Receiver and Air Traffic Control Radar Beacon System (ATCRBS) and DABS Processor Subsystem Tests," dated December 1980.

DISCUSSION

DESCRIPTION OF EQUIPMENT.

The following paragraphs present a brief description of the systems and equipment used to determine the Mode S surveillance characteristics.

MODE S. The Mode S is a cooperative surveillance and communication system for ATC. Each Mode S transponder-equipped aircraft is assigned a unique discrete address which provides a surveillance interrogation and reply protocol that inherently supports data link communications to or from that particular aircraft. In order to provide for an evolutionary transition from an all ATCRBS environment to one consisting of Mode S, the Mode S sensor operates in both an ATCRBS and Mode S mode. The sensor uses the available processing time (channel time), first for ATCRBS functions, and then for Mode S functions.

The sensor employs a monopulse direction finding technique using a 5-foot vertical aperture beacon antenna having sum, difference, and integral omnidirectional patterns. The interrogation is transmitted on the sum pattern and the reply received on the sum and difference patterns. The ratio of the amplitudes of the signals received on the difference and the sum patterns is used to determine the off-boresight angle of the target (i.e., the angular difference between the target position and antenna point angle). The beam width of the physical antenna was 2.4° at the half-power (3 decibels (dB)) points. However, the wide beam width tests were conducted using an effective receive beam width of 3.4°. The effective receive beam width is the width as defined by the received side-lobe suppression (RSLS) signals and the range of monopulse values over which the Mode S and ATCRBS processor functions are performed. The software parameters, main beam low (MBL) and main beam high (MBH), define this useful monopulse range within the monopulse correction table. Replies outside of this effective receive beam width are disregarded.

Reliable and improved ATCRBS surveillance data are obtained with a nominal 5 "hits" per target, as contrasted to today's ATCRBS of 16 to 30 hits per target. A Mode S period is used to perform Mode S surveillance and data link communications. Mode S surveillance interrogations are scheduled in range order. In each antenna beam dwell the Mode S sensor first interrogates the Mode S aircraft furthest from it. The expected arrival time of the reply is computed and interrogation for the next furthest aircraft is scheduled in a manner that allows the replies to arrive at the sensor in sequence that precludes overlap of replies. This procedure is performed for all Mode S targets, within the horizontal and vertical pattern of the antenna, until a valid roll-call reply is received from each aircraft.

Only aircraft on the sensors' roll-call list can be discretely interrogated. To acquire an aircraft on the sensor's roll-call list, Mode S transmits an ATCRBS/

Mode S All-Call interrogation, which is similar to today's ATCRBS interrogation with an additional pulse — P4. An ATCRBS transponder is unaffected by the presence of the P4 pulse and responds with a normal ATCRBS reply. Mode S transponders recognize the interrogation as a Mode S All-Call interrogation and respond with an All-Call reply containing its discrete address.

After determining the position and velocity of a Mode S transponder equipped aircraft, the sensor places the target on its roll-call list. On a subsequent discrete interrogation, the Mode S transponder can be locked out from replying to All-Call interrogations, thereby, eliminating unwanted replies. In the ATCRBS mode, the sensor transmits a P2 suppression pulse on the omnidirectional antenna each time there is an All-Call interrogation. This is accomplished in order to suppress ATCRBS transponders outside of the antenna main beam. In Mode S, each discrete interrogation consists of a preamble of P1 - P2 suppression pulse pairs to suppress ATCRBS transponders that are in the antenna main beam when the particular Mode S target is being interrogated. This intentional suppression (nominally 35 microseconds) is to prevent unwanted ATCRBS replies that may interfere with the discrete reply.

The sensor functional block diagram is depicted in figure 1. A detailed description of the sensor functions is presented in report No. FAA-NA-79-52.

AIRCRAFT REPLY INTERFERENCE ENVIRONMENTAL SIMULATOR (ARIES). The ARIES was designed by Lincoln Laboratory to simulate Mode S and/or ATCRBS target replies, ATCRBS fruit replies, COMM messages, and radar data. The ARIES equipment consists of interrogation receiving circuitry, reply generation circuitry, and a computer with associated peripheral equipment to control the system. The interrogation interface between the sensor and the ARIES was at the radiofrequency (RF) level. Replies generated by the ARIES were input to the Mode S at the receiver intermediate frequency (IF) level. Radar interface was accomplished via the Mode S communications subsystem. A complete description of ARIES is contained in Lincoln Laboratory report No. ATC-87, "Aircraft Reply and Interference Environment Simulator," dated March 22, 1979.

Simulated Mode S/ATCRBS aircraft were input to ARIES memory via magnetic tape scenarios. Along with simulated traffic, ARIES generated a simulated ATCRBS fruit environment. For both the simulated transponder replies and fruit replies, ARIES provides the necessary signals to accurately simulate the monopulse off-boresight angle. Also, an omnidirectional signal was provided so that side-lobe replies could be simulated. The sensor is able to add these signals to real world signals from the sensor's antenna to allow a simulated environment to be superimposed on a real environment.

In addition to the beacon data, ARIES provided simulated digitized radar data corresponding to the simulated beacon targets. The reported coordinates were those that would be seen by a primary radar whose antenna rotates with the beacon antenna about the same axis.

MODE S ASYNCHRONOUS REPLY GENERATOR (FRUIT). The Mode S fruit generator was designed and fabricated by FAA Technical Center personnel and provided repeatable pseudo-random Mode S replies input to the internal Mode S RF test unit (RFTU). The output of the RFTU, an RF signal, was input to the Mode S receiver and appeared to the Mode S as fruit replies from Mode S transponders. Fruit rates, long and short

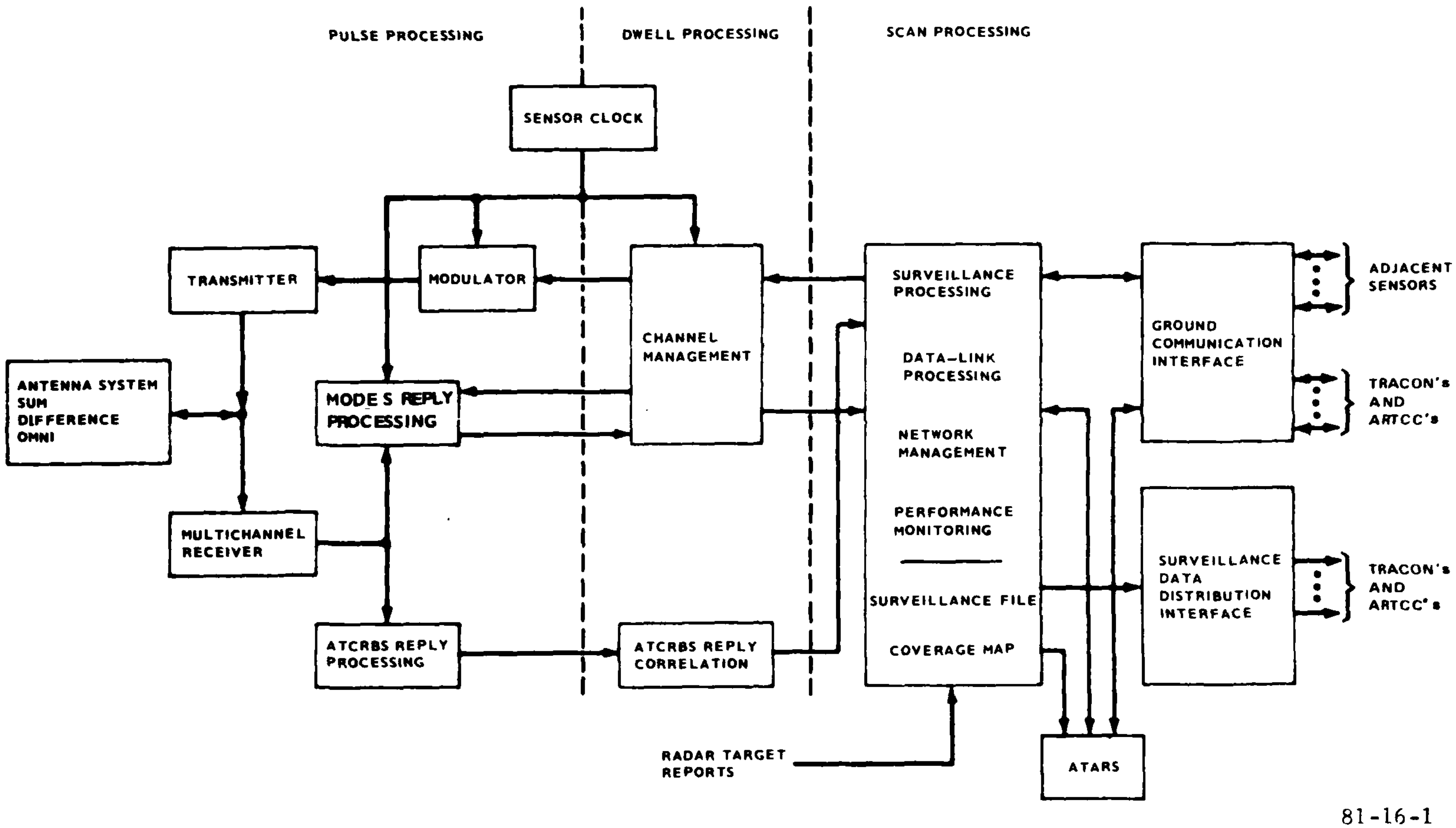


FIGURE 1. MODE S SENSOR FUNCTIONAL BLOCK DIAGRAM

reply mixtures (56- and 112-bit messages), and bit configurations were switch selectable on the reply generator.

The Mode S message output from the asynchronous reply generator was a serial data stream of either 56 or 112 μs in duration. There were 14 unique 112-bit messages. All of the simulated replies represented messages that can occur in a live environment. Each message contained the correct address/parity field.

ANTENNA CONFIGURATION. The beacon antenna originally planned to support testing of the Mode S engineering model was to have a gain of 25 dB above isotropic and a 3 dB beam width of 4°. However, in order to satisfy a recent Airway Facilities implementation requirement, an ATCRBS 5-foot antenna with a nominal gain of approximately 22 dB above isotropic and a 3 dB beam width of 2.4° was used. The ATCRBS 5-foot antenna has an array of 35 columns of 10 dipoles each and provides improved system performance because of its shaped elevation pattern and sharp horizon rolloff.

The terminal sensor utilized one of these ATCRBS antennas and the en route sensor utilized two antennas mounted in a back-to-back configuration.

CALIBRATION PERFORMANCE MONITORING EQUIPMENT (CPME). The CPME is a special purpose test transponder used to verify Mode S sensor monopulse azimuth accuracy, to calibrate the sensor off-boresight azimuth look-up table, and for checking Mode S data link integrity. It provides a method for performing a full loop system check. The CPME is permanently installed at a surveyed location within the coverage pattern of one or more Mode S sensors and is assigned its own Mode S discrete address. The positional accuracy of the CPME site is to a second-order survey having an angle accuracy of ±0.0028°, a direction accuracy of ±5 feet, and an elevation accuracy of ±1 foot. The CPME responds to ATCRBS mode 3/A and mode C interrogations and to all Mode S interrogations, except for extended length messages (ELM). The CPME is contained within a weatherproof enclosure which permits it to operate unattended over a wide range of environmental conditions. A complete description of the CPME is contained in report No. FAA-RD-78-151, "The DABS Calibration Performance Monitoring Equipment," dated March 1979.

METHOD OF APPROACH.

Evaluation of the surveillance characteristics of the Mode S en route and terminal configured sensors were conducted in two phases:

1. Phase I evaluated the baseline surveillance characteristics of both sensors utilizing an effective receive beam width of 2.4° and Mode S single site software release 6.3. It is to be noted that the terminal sensor baseline T&E had previously been performed and documented in report No. FAA-NA-79-52.

2. Phase II evaluated the surveillance characteristics of both sensors utilizing an effective receive beam width of 3.4° and Mode S software release 7.2.

This report presents a comparison of the performance of the terminal and en route configured sensors under narrow beam baseline testing, and then compares the terminal sensor in both narrow and wide beam configuration. The report concludes by presenting a comparison of both sensors under wide beam testing. The method of testing is described in the following paragraphs; a block diagram of the test environment is presented in figure 2.

SITE ADAPTABLE PARAMETERS. There were approximately 400 parameters associated with Mode S that were adaptable by means of a software entry. Those which were changed between narrow beam and wide beam testing are summarized in table 1. The remainder of the 400 parameters were maintained at the nominal values at which they were set when the sensor was delivered, except for several associated with the performance monitor.

The pulse repetition frequency (PRF) for the ATCRBS mode was fixed during Phase I testing at 128 for the terminal sensor and 64 for the en route sensor. A jitter PRF with an average equal to the Phase I fixed PRF was employed during Phase II testing in accordance with the sequence shown in table 1. This jitter PRF was used to reduce the possibility of interference from the Clementon Mode S sensor, operating with the same PRF and antenna scan rate as the Technical Center sensor.

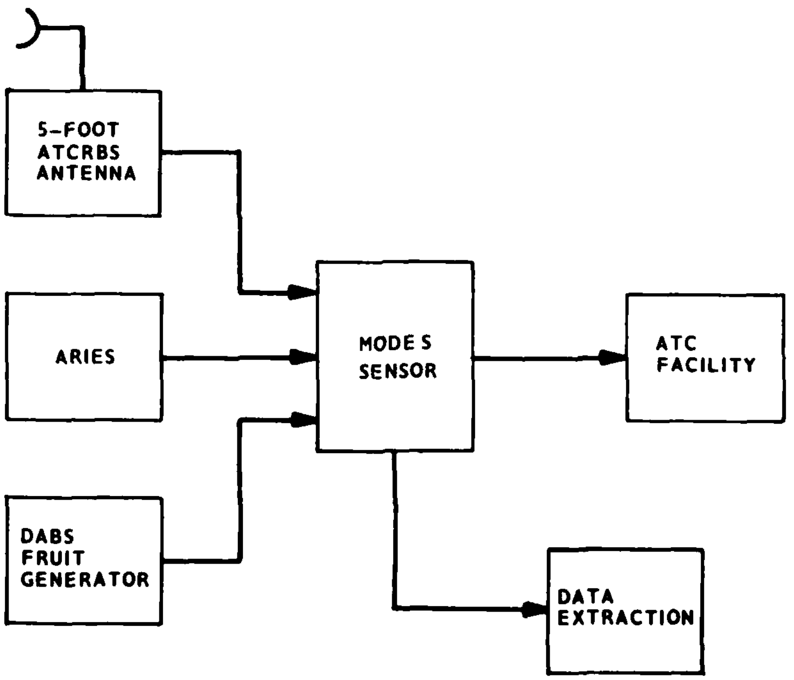


FIGURE 2. TEST ENVIRONMENT

TABLE 1. SITE ADAPTABLE PARAMETER CHANGES

Parameter	Terminal Sensor Phase I	Terminal Sensor Phase II	En Route Sensor Phase I	En Route Sensor Phase II
*Antenna Scan Rate	12.85 rpm 4.67 sec/scan	12.85 rpm 4.67 sec/scan	6.27 rpm 9.57 sec/scan	6.27 rpm 9.57 sec/scan
Sensor Load Tape Release	6.3	7.2	6.3	7.2
Effective Receive Beam Width	2.4°	3.4°	2.4°	3.4°
Main Beam Low (MBL) (Monopulse Index)	41	25	44	31
Main Beam High (MBH) (Monopulse Index)	215	236	215	232
Pulse Repetition Frequency (PRF)	128 (fixed)	128 (jitter)	64 (fixed)	64 (jitter)
Sequence of PRF Period	7.8 ms	5 @ 7.50 ms 1 @ 9.37 ms	15.62 ms	2 @ 15.50 ms 1 @ 15.87 ms 2 @ 15.50 ms 1 @ 15.87 ms

*Presented for reference information only — not an actual parameter change.

Note: rpm = revolutions per minute
ms = milliseconds

During baseline testing with software release 6.3, report-to-track association/correlation functions were both performed prior to ATC dissemination. Report data were disseminated to both correlating users (i.e., system support facility (SSF)), and noncorrellating users (i.e., terminal automated test facility (TATF)). The Technical Center data reduction and analysis (DR&A) program used during baseline testing analyzed the ATC messages disseminated to the SSF correlating user. In an effort to improve the Mode S sensors throughput, the contractor modified release 7.2 to allow dissemination before report-to-track correlation was completed. If certain criteria (a unique correlation) for a report were not met, correlation was deferred and the ATC report was disseminated to correllating users (SSF) immediately without a track number assigned. The report-to-track correlation was deferred and dissemination to noncorrelating users (TATF) was delayed by at least four sectors.

SURVEILLANCE CHARACTERISTICS. The following seven performance criteria were selected to portray the surveillance characteristics of the sensors:

1. Percent of detection (Pd) of ATC disseminated messages.

2. ATCRBS Mode 3/A code reliability of ATC disseminated messages.

3. Mode S identifier (ID) reliability of ATC disseminated messages.

4. Altitude code reliability of ATC disseminated messages.

5. The number of replies per report for ATCRBS targets.

6. The number of interrogations per scan for Mode S targets.

7. Blip scan ratio (b/s).

Definitions of these parameters and how they are calculated are presented for clarification:

PERCENT DETECTION. The number of scans in which a target report for any given aircraft is provided by the Mode S sensor, divided by the total number of elapsed scans over which the Pd is being measured.

$$\text{Pd} = \frac{\text{Number of scans a target report was provided by Mode S}}{\text{Total number of scans a target is being analyzed}}$$

CODE RELIABILITY. The number of times a target with the correct code was detected, divided by the total number of times the target was detected.

$$\text{ATCRBS Mode 3/A Code Reliability} = \frac{\text{Number of times target was detected with correct Mode 3/A code}}{\text{Total number of times target was detected}}$$

$$\text{Mode S Reliability} = \frac{\text{Number of times target was detected with correct Mode S ID}}{\text{Total number of times target was detected}}$$

$$\text{Altitude Code Reliability} = \frac{\text{Number of times target was detected with correct altitude code and all high-confidence bits set}}{\text{Total number of times target was detected}}$$

BLIP SCAN RATIO. The number of times the surveillance file for track is updated, divided by the sum of the number of updates, plus the number of coasts. A track update may be from beacon data or radar data.

$$b/s = \frac{\text{Number of updates}}{\text{Number of updates + number of coasts}}$$

Coasts are defined as scans for which neither a beacon nor radar report exists for a particular aircraft track.

Surveillance characteristics were determined using simulated ATCRBS and Mode S targets and fruit replies from ARIES as inputs to the sensors. The test matrix is shown in figure 3. Three types of test scenarios were designed and generated for use with ARIES:

1. The Basic 42 Scenario. Designed to simulate a variety of aircraft flight patterns. These profiles included aircraft crossings at various intersecting angles, overtaking, head-on, north crossings, transitions through the zenith cone, track swap possibilities, and targets in the clear.

2. The Turning Scenario. Designed to present targets which were only experiencing turning attitudes.

3. Signal Strength Scenario. Designed to characterize the surveillance performance as a function of sensor input signal level. The ARIES output power varies as a function of aircraft range measured from the origin. Therefore, targets having a constant range for various ranges within 60 nautical miles (nmi) were employed to develop signal levels that resulted in a percent detection between 0 and 100 percent.

Each of these scenarios were generated as either all Mode S, all ATCRBS, or a mixture of the two types. Separate scenarios were generated for the terminal and the en route sensor.

TARGET AND ENVIRONMENTAL VARIABLE PARAMETERS. In addition to the scenarios, variable target and environmental parameters were also input to the sensor. The following paragraphs describe these parameters and give the rationale for the values selected for testing.

Beacon Round Reliability. Beacon R/R is the percentage of replies received from an aircraft compared to the number of interrogations directed to the aircraft. During the generation of the ARIES scenarios the R/R for each of the targets was predetermined by selection of a reply probability for each aircraft.

The values of 0.93 and 0.70 were chosen as test inputs for all except the turning scenarios. Turning scenarios had an R/R of 1.0 and 0.70. An R/R of 0.93 or greater was representative of the real world. An R/R of 0.70 was used to test sensor performance at a very low R/R.

Radar Blip Scan. The radar b/s is the likelihood of receiving a radar report from a selected target on a given scan. It has the same value for all targets within a specific scenario and is established by setting parameters in the ARIES environmental file on the disk.

FIGURE 3. SURVEILLANCE TEST MATRIX FOR EFFECTIVE RECEIVE BEAM WIDTH OF 3.4°

Test No.	Sensor Under Test	Req. Probability	Simulated Aircraft Type	Replies Per Second ATCRBS	Replies Per Second Mode S	Radar Blip Scan
(Basic Aircraft Scenario)						
P-1	Terminal	0.93	ATCRBS	0		0.8
P-2	Terminal	0.93	Mode S	0		0.8
P-3	Terminal	0.93	Mixed	0		0.8
P-4	Terminal	0.93	A	4,000	0	0.8
P-5	Terminal	0.93	A	44,000		0.8
P-6	Terminal	0.93	S	0	50	0.8
P-7	Terminal	0.93	S	0	200	0.8
P-8	Terminal	0.93	M	4,000	50	0.8
P-9	Terminal	0.93	M	44,000	200	0.8
P-10	Terminal	0.70	A	0	0	0.8
P-11	Terminal	0.70	S	0	0	0.8
P-12	Terminal	0.70	M	0	0	0.8
P-13	Terminal	0.70	A	4,000		0.8
P-14	Terminal	0.70	A	44,000	0	0.8
P-15	Terminal	0.70	S	0	50	0.8
P-16	Terminal	0.70	S		200	0.8
P-17	Terminal	0.70	M	4,000	50	0.8
P-18	Terminal	0.70	M	44,000	200	0.8
P-19	En route	0.93	A		0	0.8
P-20	En route	0.93	S	0	0	0.8
P-21	En route	0.93	M	0	0	0.8
P-22	En route	0.93	A	4,000	0	0.8
P-23	En route	0.93	A	13,300	0	0.8
P-24	En route	0.93	S	0	50	0.8
P-25	En route	0.93	S	0	200	0.8
P-26	En route	0.93	M	4,000	50	0.8
P-27	En route	0.93	M	13,300	200	0.8
P-28	En route	0.70	A			0.8
P-29	En route	0.70	S	0	0	0.8
P-30	En route	0.70	M	0	0	0.8
P-31	En route	0.70	A	4,000	0	0.8
32	En route	0.70	A	13,300		0.8
P-33	En route	0.70	S	0	50	0.8
P-34	En route	0.70	S	0	200	0.8
P-35	En route	0.70	M	4,000	50	0.8
P-36	En route	0.70	M	13,300	200	0.8
(Turning Aircraft Scenario)						
P-37	Terminal	1.0	ATCRBS	0		0.8
P-38	Terminal	1.0	A	4,000	0	0.8
P-39	Terminal	1.0	A	44,000		0.8
P-40	Terminal	1.0	Mode S	0	0	0.8
P-41	Terminal	1.0	S	0	50	0.8
P-42	Terminal	1.0	S	0	200	0.8
P-43	Terminal	0.70	A	0	0	0.8
P-44	Terminal	0.70	A	4,000	0	0.8
P-45	Terminal	0.70	A	44,000	0	0.8
P-46	Terminal	0.70	S	0	0	0.8
P-47	Terminal	0.70	S	0	50	0.8
P-48	Terminal	0.70	S	0	200	0.8
P-49	En route	1.0	A	0	0	0.8
P-50	En route	1.0	A	4,000	0	0.8
P-51	En route	1.0	A	13,300	0	0.8
P-52	En route	1.0	S	0	0	0.8
P-53	En route	1.0	S	0	50	0.8
P-54	En route	1.0	S	0	200	0.8
P-55	En route	0.70	A	0	0	0.8
P-56	En route	0.70	A	4,000	0	0.8
P-57	En route	0.70	A	13,300	0	0.8
P-58	En route	0.70	S	0	0	0.8
P-59	En route	0.70	S	0	50	0.8
P-60	En route	0.70	S	0	200	0.8
(Signal Strength Scenario)						
P-61	Terminal	0.95	ATCRBS	0	0	0
P-62	Terminal	0.95	A	44,000	0	0
P-63	Terminal	0.95	Mode S	0	0	0
P-65	Terminal	0.95	S	0	200	0

Note: A = ATCRBS
S = Mode S
M = Mixed

Radar b/s of 0.8 was used for the Basic 42 and turning scenarios; zero was used for the signal strength scenario. The zero radar blip scan represents beacon reports only while the 0.8 radar blip scan was employed to be representative of that presently encountered in a real world environment.

ATCRBS ASYNCHRONOUS REPLIES FRUIT. The ATCRBS fruit added to the scenarios were generated by ARIES. The fruit rate, as selected in the ARIES environmental file, represents the total fruit which would enter a directional antenna. A second parameter, the main beam/side-lobe ratio, defines what percentage of total fruit received by the directional antenna occurred within the antenna main beam. Measurements of real world fruit (at the Technical Center ASR-7 facility), using the ATCRBS 5-foot antenna and the Mode S sensor, indicated a fruit rate between 500 to 1,000 replies per second. Of this total number, approximately 25 percent were main beam replies.

The scenario fruit rates selected for each sensor were:

Sensor	Fruit Per Second
Terminal	0; 4,000; 44,000
En Route	0; 4,000; 13,300

The 4,000 replies per second rate simulates the present fruit environment encountered in areas such as New York City or Los Angeles. The 44,000 or 13,300 rates were chosen, in accordance with the FAA-ER-240-26 capacity requirement, to generate eight main beam fruit per sweep within the 60 or 200 nmi range of the respective terminal or en route facility.

MODE S ASYNCHRONOUS REPLIES FRUIT. The Mode S fruit added to the scenarios were generated by the Mode S asynchronous reply generator. All of these fruit replies were in the main beam of the antenna and comprised of 56- and 112-μs message lengths having a mixture of 75 percent and 25 percent, respectively. Three Mode S fruit rates of 0, 50, and 200 replies per second were selected for baseline simulation tests.

DATA PROCESSING. The following paragraphs describe the methods used for extracting, reducing, and analyzing the data collected during the T&E.

Mode S Data Extraction. The information collected included the track report data block, surveillance report data block, and the ATC report data block. The data blocks contained the following types of information: time of day, target ID, target ID confidence, altitude, altitude confidence, range, azimuth, range rate, azimuth rate, predicted range and azimuth, firmness, and radar flags to indicate if the report was radar reinforced, substituted, radar-only, etc.

ARIES Data Extraction. The information collected consisted of two types of data blocks: reply and radar. The reply data block contained the ARIES track number, target ID, altitude, range, azimuth, and ARIES time. The radar data block contained the ARIES track number and the range and azimuth of the target. In addition, the output tape had explanation codes for ARIES aircraft not responding to sensor interrogations.

Data Reduction and Analysis. Several computer programs were developed at the Technical Center to correlate the Mode S data with the ARIES data. Since the inputs to the Mode S sensor were known from the data recorded on the ARIES data extraction tape, sensor performance was characterized by a comparison of the two data tapes.

The ARIES/Mode S report analysis program compared Mode S reports with those generated by ARIES. Since the ARIES tape contained only replies for each target, the program computed a report from the replies using a simple algorithm. In order to make a positive comparison between ARIES and Mode S, a window was defined around the ARIES target having the following restrictions: (1) range difference of 0.045 nmi or less, (2) azimuth difference of 0.8° or less, and (3) a time difference of 0.15 seconds or less. Since the ARIES targets are input to the analysis program, it was easy to determine, within the above window limits, which targets the sensor failed to detect. This performance parameter is the Pd, as previously defined. In a similar manner, the code reliabilities, as previously defined, were also computed.

The last performance parameter analyzed for ATCRBS aircraft was the number of replies from which the report was generated. These data were recorded in the Mode S report. For Mode S aircraft, the average number of roll-call interrogations per scan were computed. Other statistics of interest output from the program are: (1) the number of extra reports generated by Mode S from either fruit or split reports, (2) the mean and standard deviation of the range difference between ARIES and Mode S, and (3) the mean and standard deviation of the azimuth difference.

The program printed out error messages indicating where problems occurred that may have impacted the above statistics. In addition, the raw data for both the ARIES and Mode S reports were output as an aid in further investigation. The program output summarized the above parameters over a specific number of scans for each aircraft in the scenario.

After the data reduction programs summarized the performance parameter data for each aircraft, a subset of these data was selected to characterize sensor performance under various environmental parameters. This was accomplished for each of the scenarios.

The aircraft in the Basic 42 scenarios were categorized as follows: (1) clear-air or straight flight targets, (2) zenith cone or close-in targets, and (3) conflicting tracks. The scan numbers, at which the encounters took place for each aircraft in the above categories, were determined. Scan numbers for the clear-air targets were selected to provide a sufficiently large sample size. The zenith cone scans were selected to include six scans before and six scans after entering the zenith cone. For aircraft in a conflict (crossing or overtaking) situation, only the scans of data within the actual conflict were analyzed. Two aircraft were considered to be in conflict if they were within 1.6 nmi and 2.4° of each other. The scan numbers for the turning tracks were selected such that the data analyzed included the entire turn plus three scans after the turn.

Table 2 identifies the track number, the assigned category, and the scans which were selected for each of the scenario aircraft.

TABLE 2. AIRCRAFT SCENARIO DATA REDUCTION AND ANALYSIS CRITERIA

Category	ARIES Track No.	Sensor Scan No. Terminal	En Route
Clear Air	3	110-139	53-69
	39	4-30	1-14
	40	4-30	1-14
	41	4-30	1-14
	42	4-30	1-14
Zenith Cone	38	26-53	12-26
	6	61-100	29-49
	7	219-236	107-116
Conflicts	5	122-137	60-68
	15	122-137	60-68
	28	25-41	12-21
	29	25-41	12-21
	1	63-76	30-38
	2	63-76	30-38
	4	63-76	30-38
	19	56-62	27-31
	20	56-62	27-31
	33	27-33	13-17
	34	27-33	13-17
	35	27-33	13-17
	23	29-97	14-48
	24	29-97	14-48
	30	40-85	19-42
	31	40-85	19-42
	17	252-263	123-129
	18	252-263	123-129
	36	74-112	36-55
	37	74-112	36-55
	11	90-106	44-52
	12	90-106	44-52
	13	90-106	44-52
Turning Aircraft	5	12-30	6-15
	6	12-27	6-14
	7	15-41	8-21
	8	14-33	7-17
	10	12-29	6-15
	11	12-29	6-15
	12	10-38	5-19
	13	15-42	8-21
	14	10-36	5-18
	15	12-31	6-16

TEST RESULTS AND ANALYSIS

The results for the Mode S en route and terminal sensors are presented in two phases. Phase I compares the surveillance characteristics of the two sensors operating with an effective receive beam width of 2.4° and Mode S single site software release 6.3. Phase II compares the surveillance characteristics of the two sensors operating with an effective receive beam width of 3.4° and Mode S multisite software release 7.2.

PHASE I TEST RESULTS.

Surveillance characteristics of the terminal sensor operating with an effective receive beam width of 2.4°, employing single site software release 6.3, had previously been documented in report No. FAA-NA-79-52. The surveillance characteristics described therein are compared in this report to the en route sensor performance for an effective receive beam width of 3.4°. This comparison is achieved for simulated clear air, conflicting, turning, and zenith cone aircraft tracks. Simulation was accomplished via ARIES using scenarios for ATCRBS or Mode S targets. The scenarios were identical at each sensor except for the sensors respective range capabilities.

The environment simulated during the Phase I testing is summarized below:

	Aircraft Track Type		
	Clear, Conflict,	Zenith Cone	Turning
Round Reliability (R/R)	0.93	0.70	1.0
Generated Fruit (replies/sec)			
ATCRBS	0 and 4,000	44,000/13,300	4,000
Mode S	0 and 50	200	50
Radar Probability	0.80	0.80	0.80

It should be noted that to assure the ER requirement of 8 fruit per sweep would not be exceeded, the maximum ATCRBS fruit rate was set at 44,000 replies per second for the terminal sensor (60 nmi) and at 13,300 replies per second for the en route sensor (200 nmi).

Comparison of the en route and terminal sensors are presented in figures 4 through 8 for surveillance characteristics of:

1. Pd
2. ATCRBS Mode 3/A code reliability
3. Mode S ID reliability
4. Altitude reliability
5. ATCRBS replies per report
6. Mode S interrogation rate
7. b/s

The Pd results for both sensors are presented in figure 4. Both sensors exhibited a Pd of betwen 99 to 100 percent for ATCRBS and Mode S targets operating with an R/R of 0.93 or better at either no fruit (figure 4A) or intermediate level of fruit (figure 4B). For an R/R of 0.7 and high fruit rate (figure 4C), the Pd of ATCRBS targets decreased approximately 15 percent for both sensors. This reduction in detection is attributed to not receiving the required two replies out of a possible four replies in the beam necessary to declare a target and possible garbling at the high fruit rate. The conflicting tracks showed the Pd for ATCRBS targets to be 5 to 6 percent less than that for clear-air tracks at the 0.7 R/R and high fruit rate.

The Pd for Mode S targets was approximately 100 percent for both sensors independent of fruit rate, R/R, and type of aircraft tracks. This result is due to Mode S only requiring one valid reply during the beam dwell to declare a target after roll-call status is established.

The results of comparing both sensors for ATCRBS Mode 3/A code and Mode S ID reliability are depicted in figure 5. The Mode S ID reliability remained at 100 percent for both sensors and was independent of fruit rate, R/R, and type of aircraft tracks. The ATCRBS Mode 3/A code reliability for an R/R of 0.93 or greater (figures 5A and 5B) ranges from 98 to 100 percent, depending upon the type of aircraft tracks being encountered. At an R/R of 0.7 and high fruit rate (figure 5C), the clear air tracks for the en route sensor have an ATCRBS Mode 3/A code reliability about 4 percent less than that of the terminal sensor. This was caused by one of the clear air targets being detected with an incorrect Mode 3/A code at the start of track initiation. The incorrect Mode 3/A detection was a result of the low R/R and high fruit rate environment.

A comparison of the alitude code reliability for both sensors is presented in figure 6. The results indicate altitude code reliability for Mode S to be 100 percent for all fruit rates, R/R, and type of aircraft tracks tested. The ATCRBS altitude code reliability for an R/R of 0.93 and greater (figures 6A and 6B) agree at both sensors to within 3 percent. Reducing the R/R to 0.7 and increasing to the high fruit rate (figure 6C) resulted in the en route sensor performing approximately 7 percent better for conflicting tracks and 3 percent better for clear-air tracks than the terminal sensor. This result is due to the greater fruit density present within the terminal sensor surveillance area as compared to the en route sensor, which results in a greater possibility of pulse garbling. Also, in order to achieve an indication of valid (100 percent reliable) altitude code reliability, all pulses within the code train must have high confidence. Since there is no feedback from tracked data to correct for low confidence altitude codes as there is for Mode 3/A code reliability, the reduced ATCRBS code reliability experienced in figure 6C can be expected.

A comparison between the two sensors for ATCRBS replies per report and Mode S interrogation rates are depicted in figure 7. The ATCRBS replies/report for both sensors agree within 5 percent for all fruit rates, R/R, and aircraft tracks. The reduction of ATCRBS replies/report between an R/R of 0.93 (figures 7A and 7B) and an R/R of 0.7 (figure 7C) is the result of simply having fewer replies to make a report due to the reduced R/R factor.

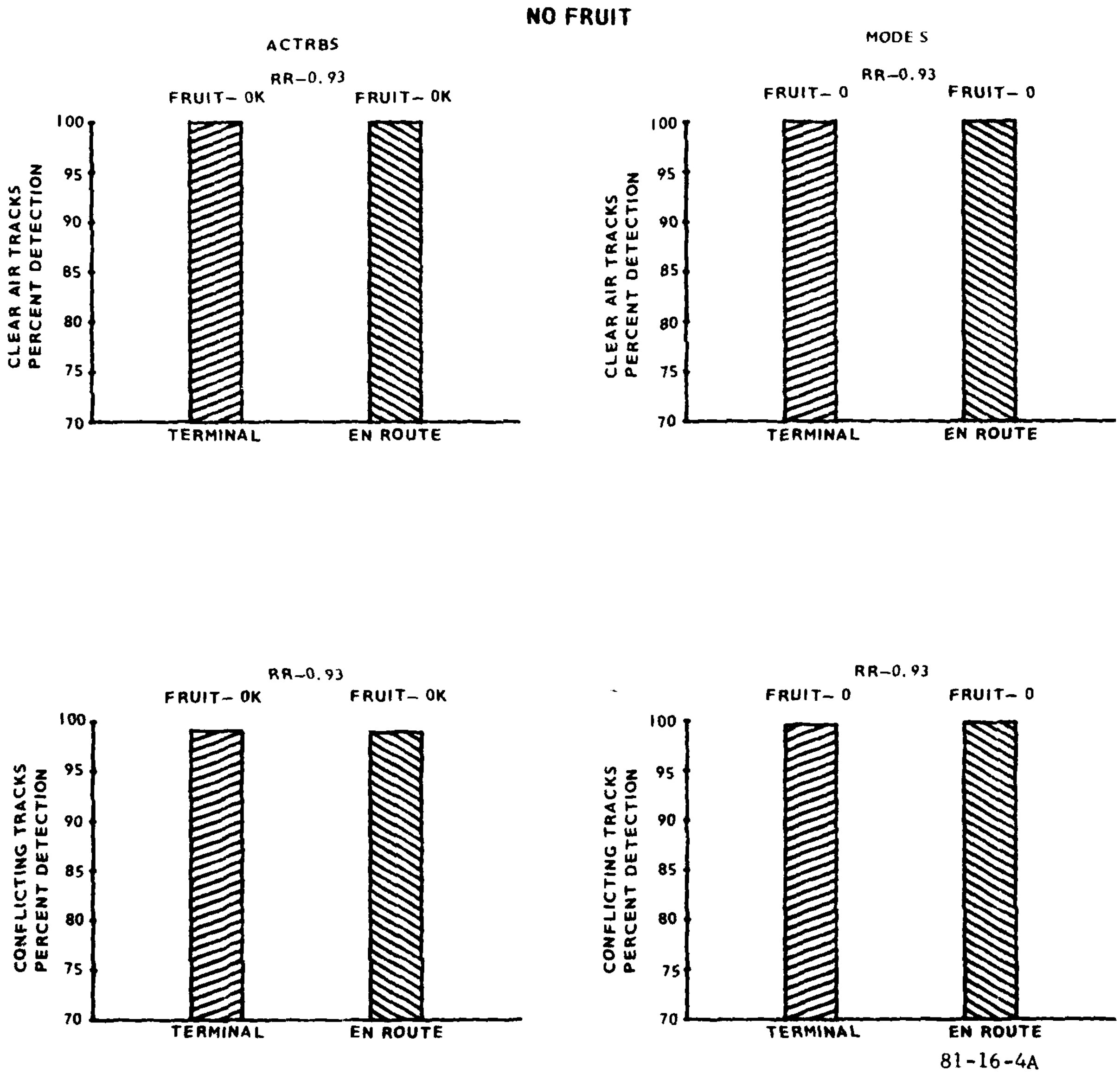


FIGURE 4. PERCENT DETECTION — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 1 of 3)

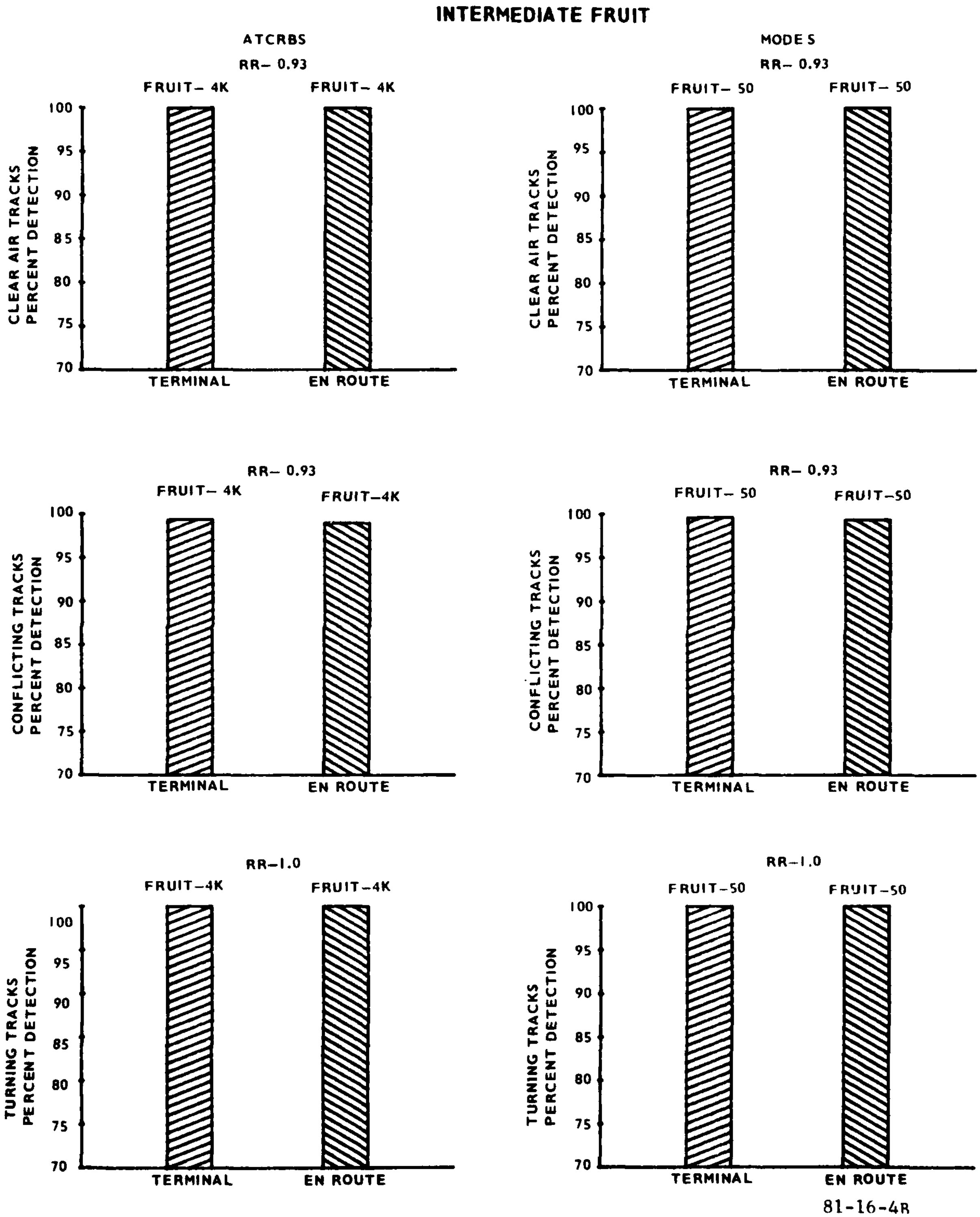


FIGURE 4. PERCENT DETECTION — TERMINAL VERSUS EN ROUTF SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 2 of 3)

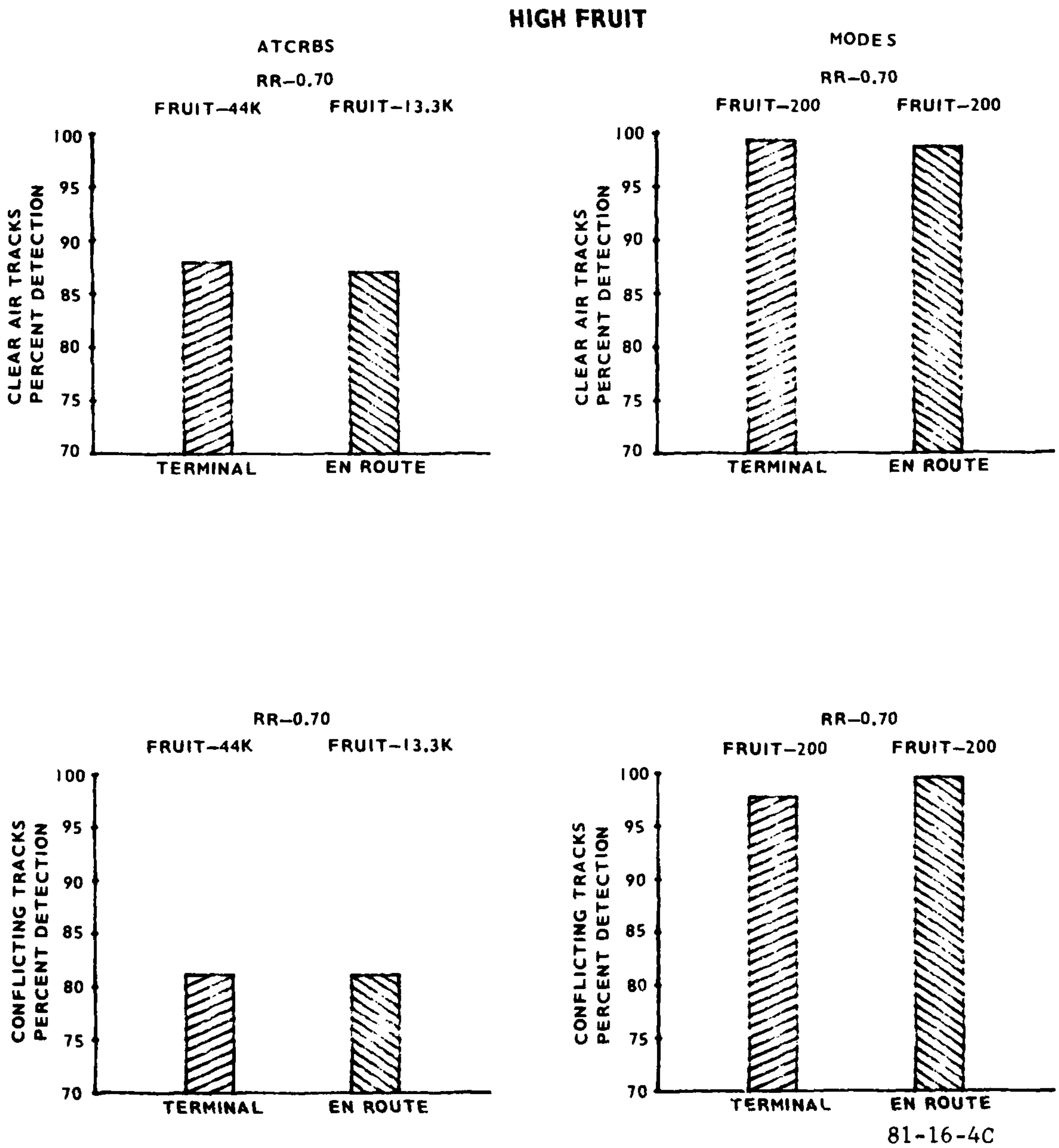


FIGURE 4. PERCENT DETECTION — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 3 of 3)

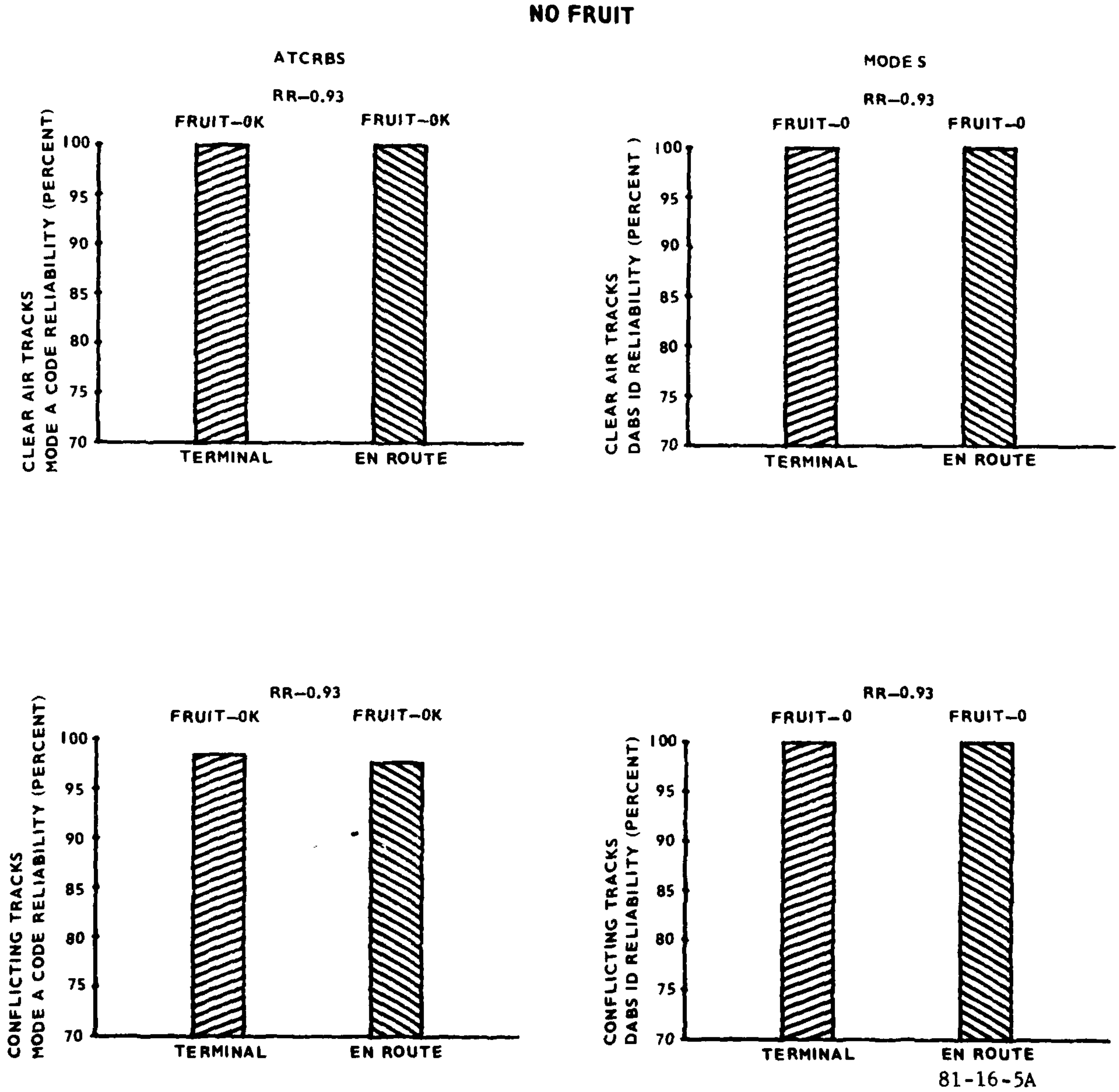


FIGURE 5. ATCRBS MODE 3/A MODE S ID RELIABILITY — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 1 of 3)

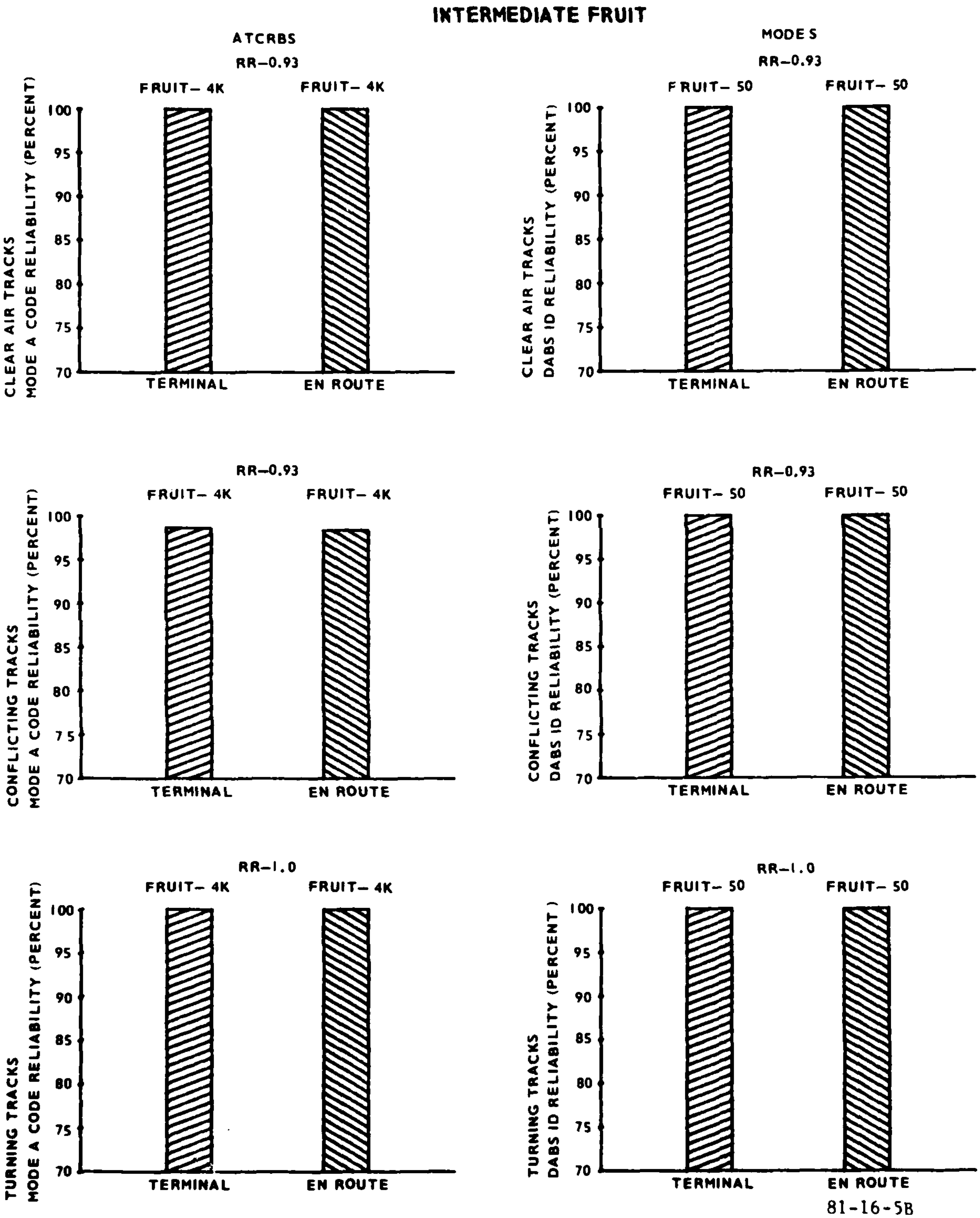


FIGURE 5. ATCRBS MODE 3/A MODE S ID RELIABILITY — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 2 of 3)

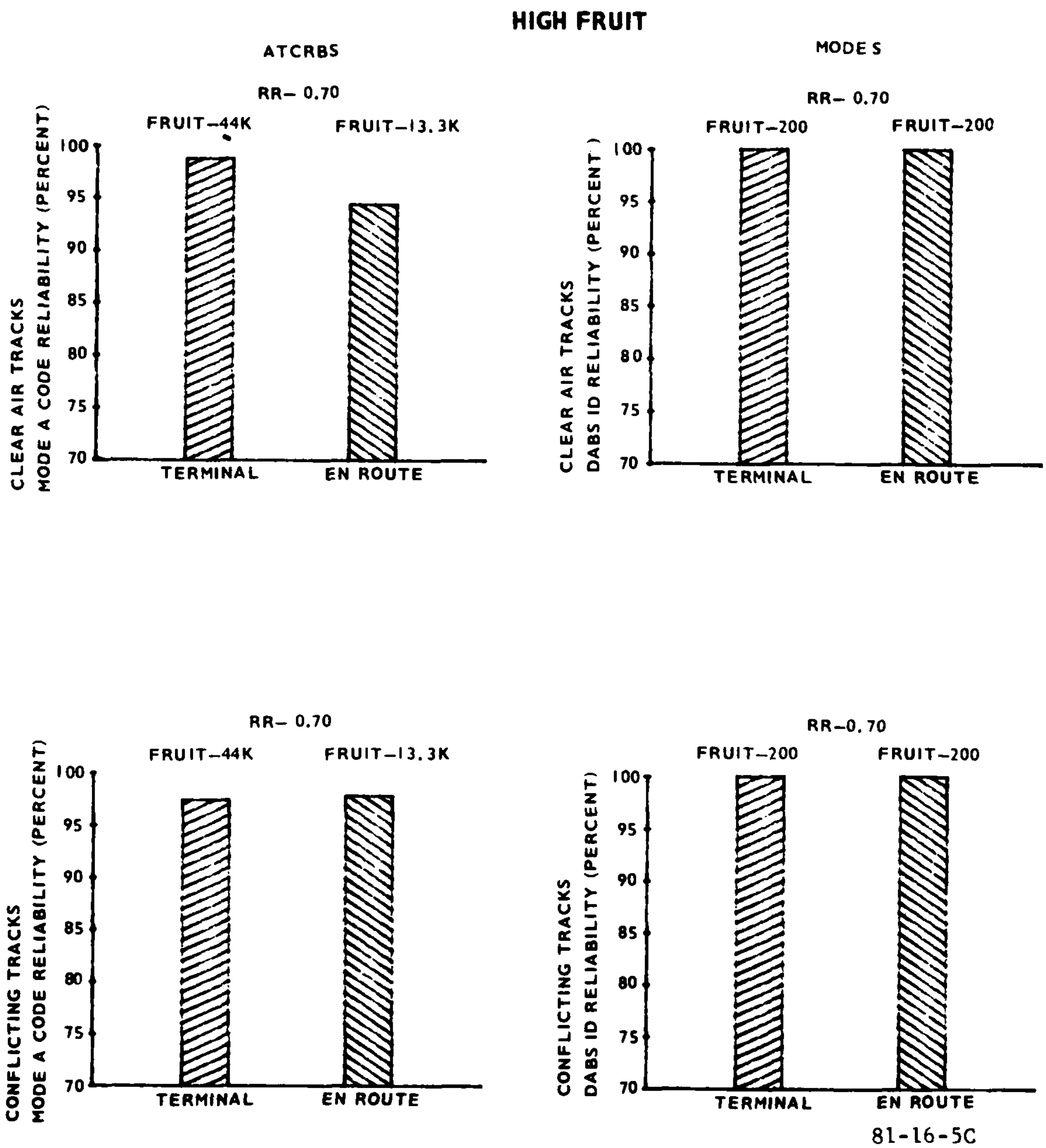


FIGURE 5. ATCRBS MODE 3/A MODE S ID RELIABILITY — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 3 of 3)

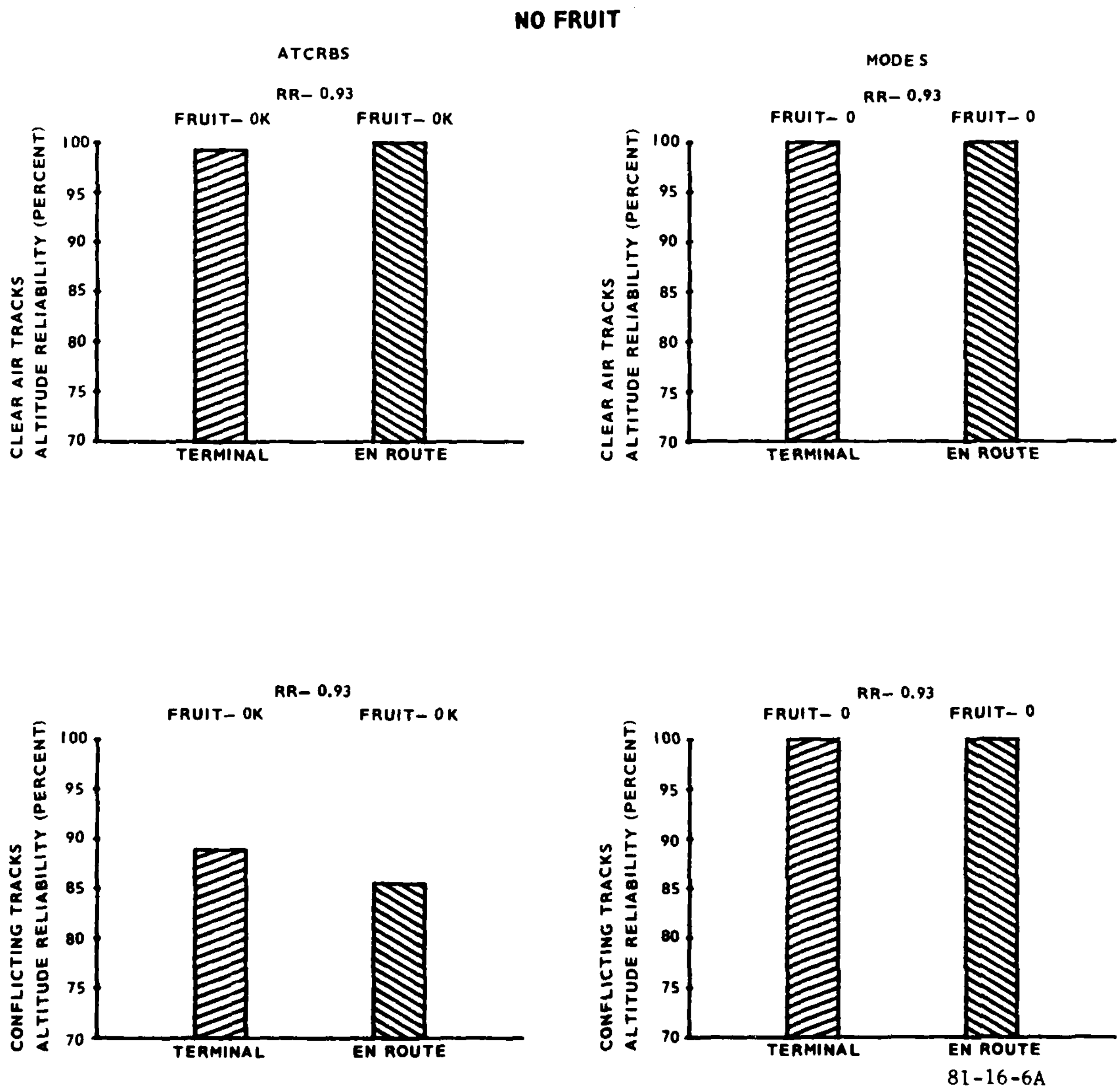


FIGURE 6. ALTITUDE RELIABILITY — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 1 of 3)

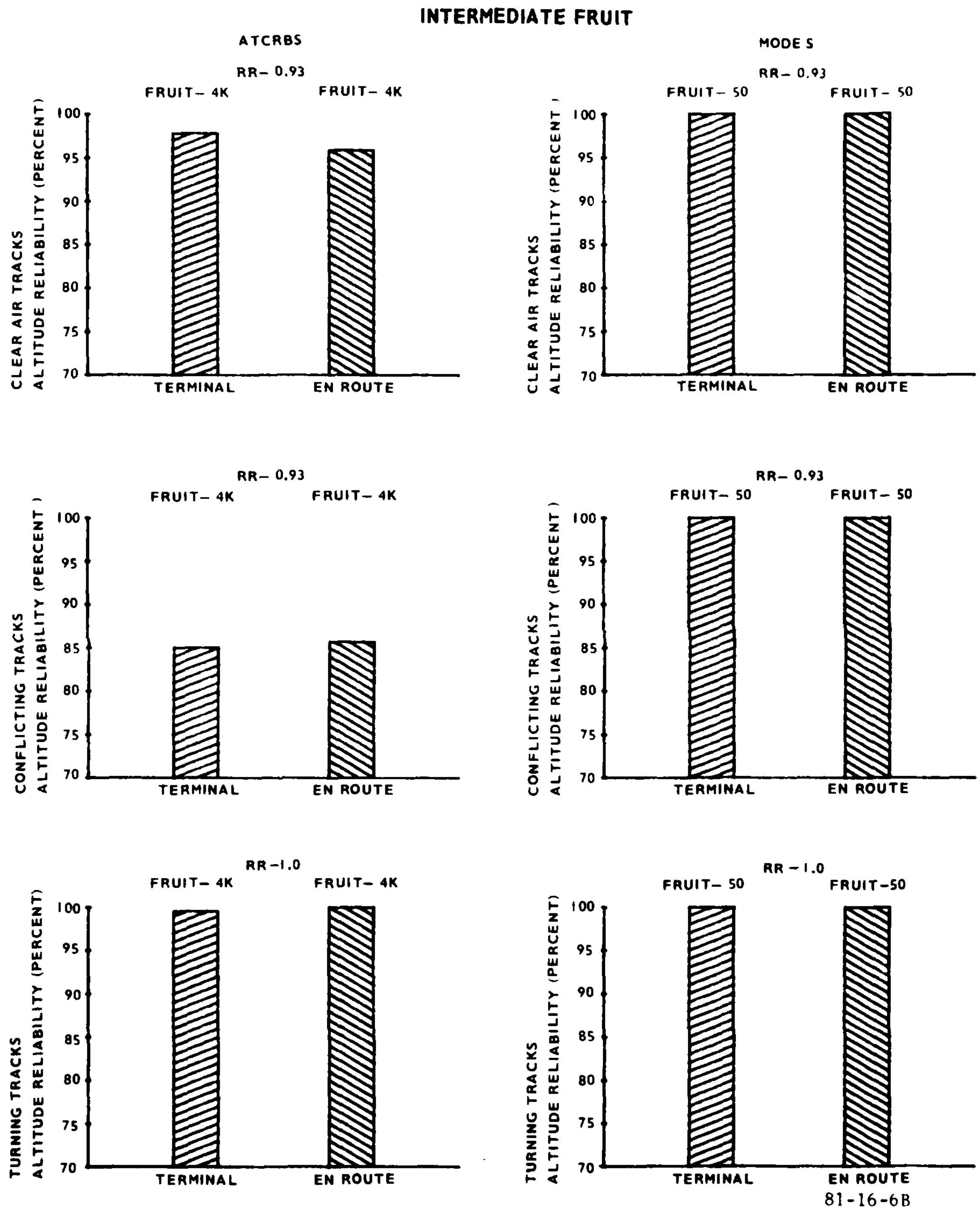


FIGURE 6. ALTITUDE RELIABILITY — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 2 of 3)

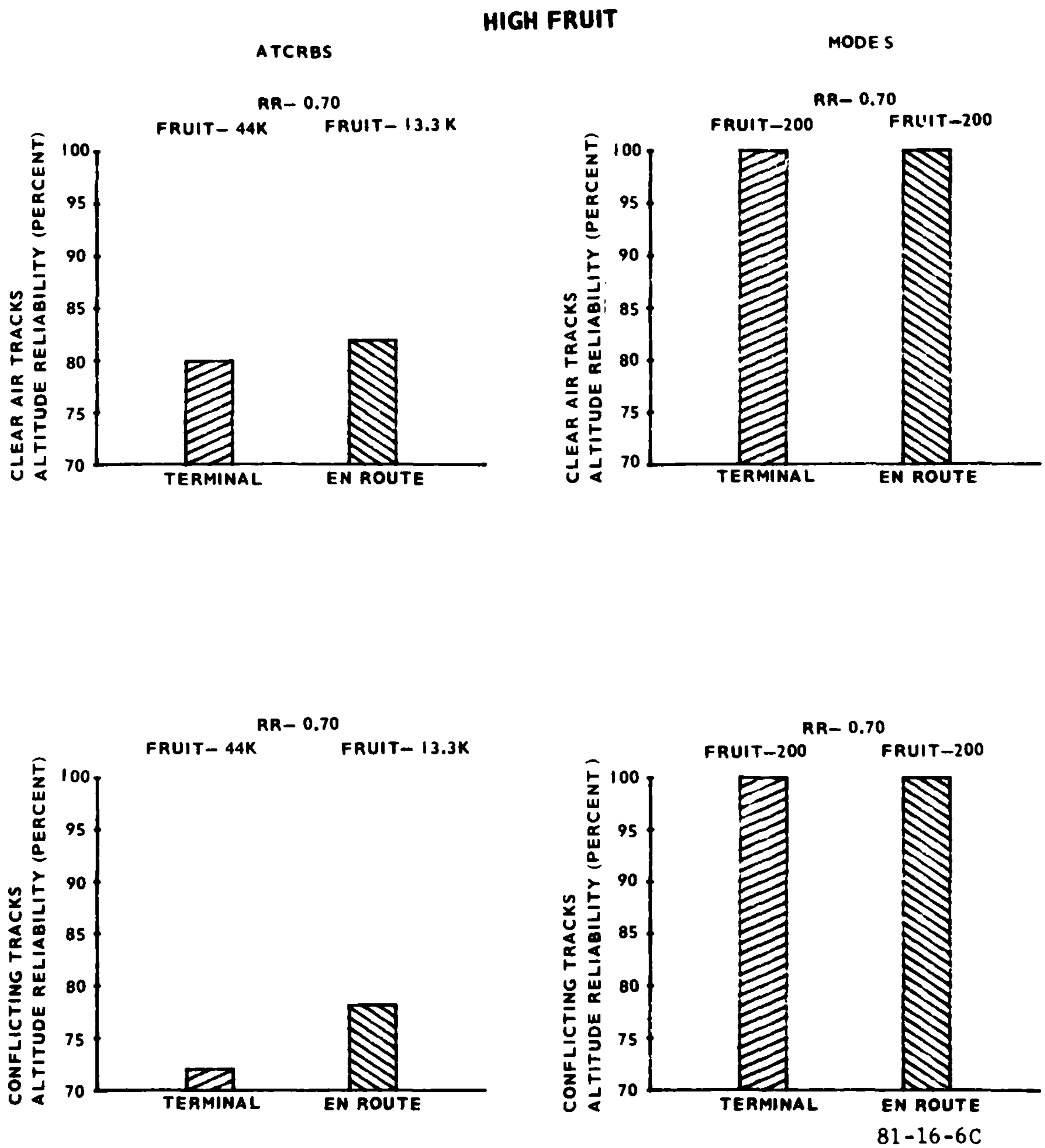


FIGURE 6. ALTITUDE RELIABILITY — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 3 of 3)

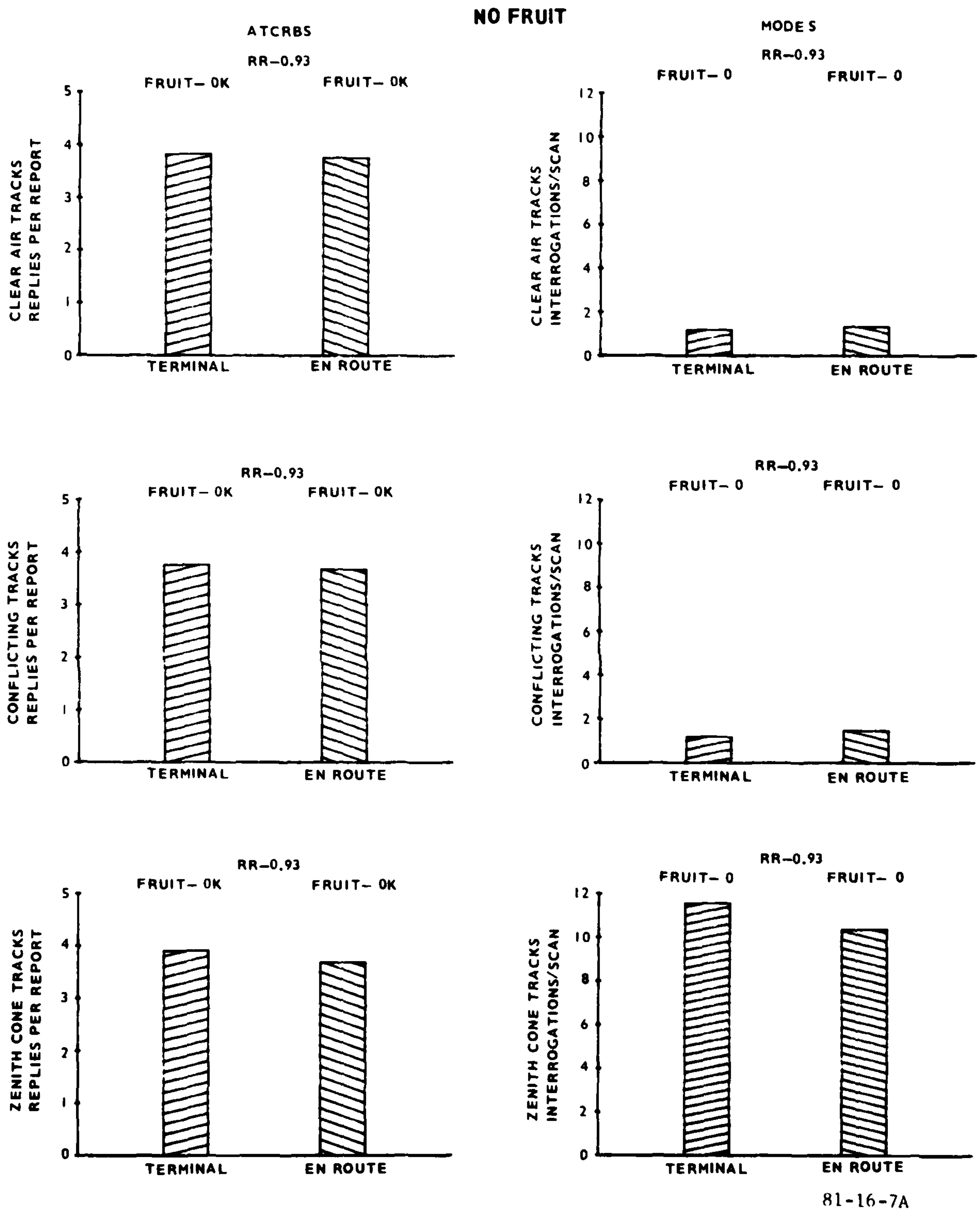


FIGURE 7. ATCRBS REPLIES PER REPORT: MODE S INTERROGATION RATE — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 1 of 3)

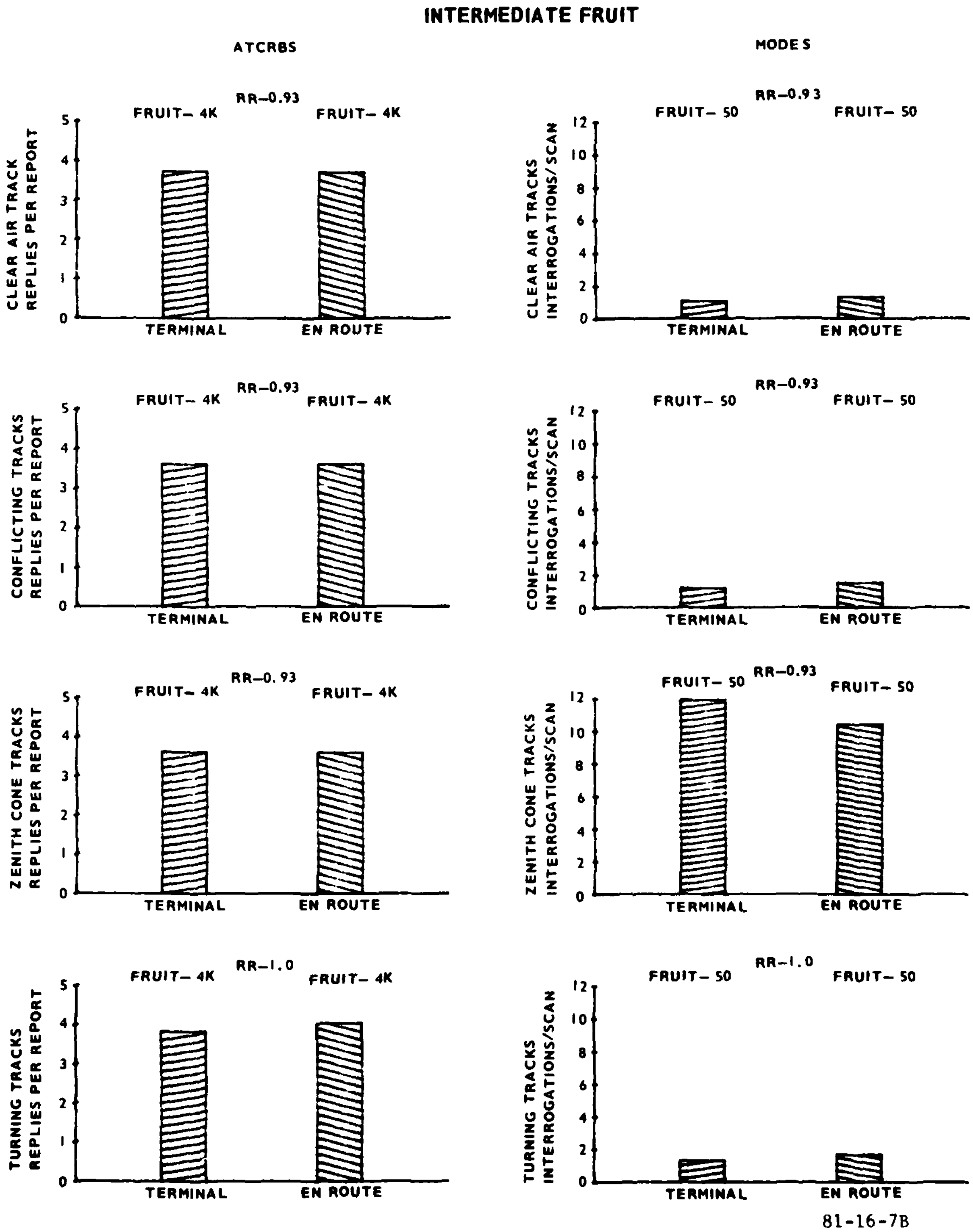


FIGURE 7. ATCRBS REPLIES PER REPORT: MODE S INTERROGATION RATE — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 2 of 3)

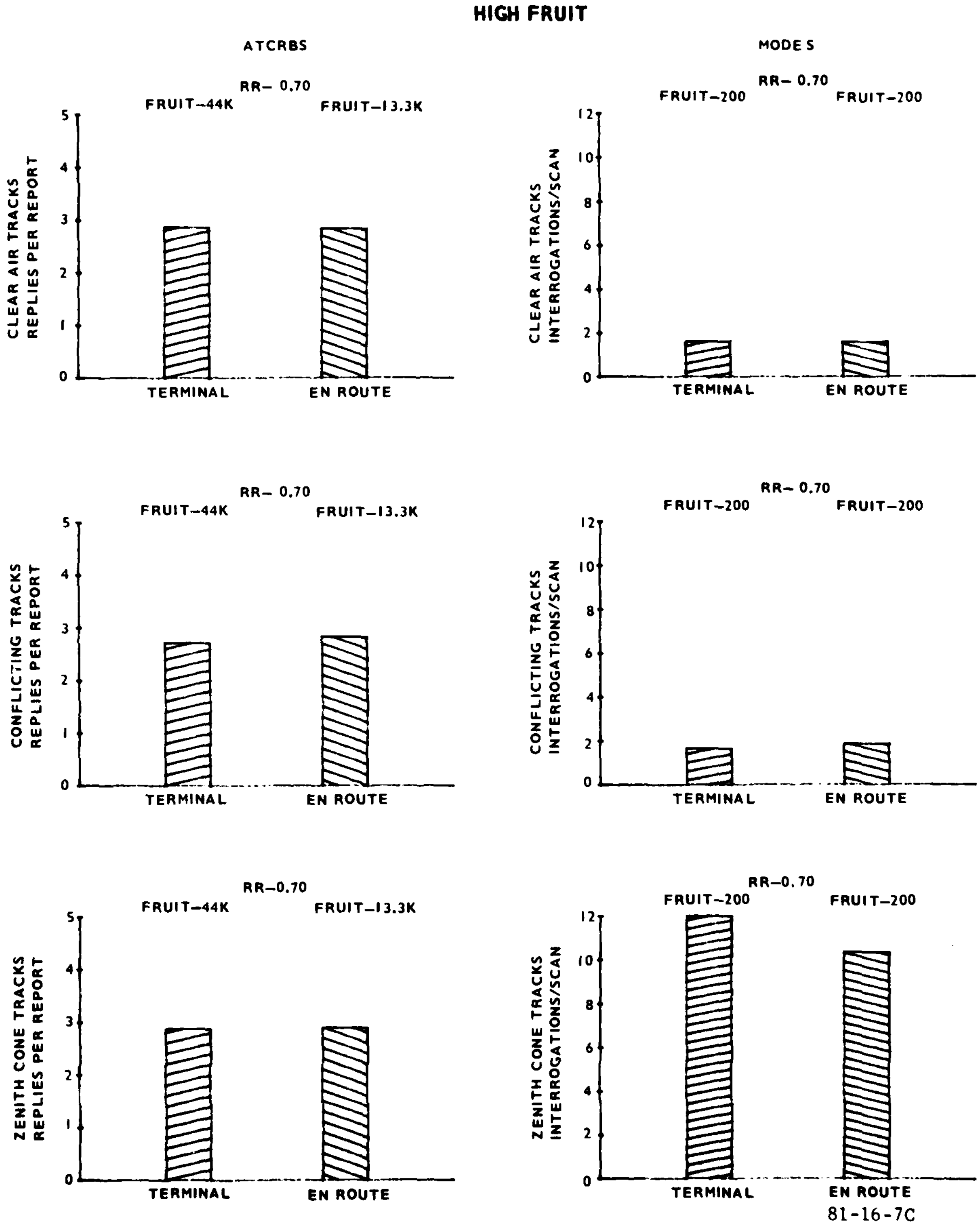


FIGURE 7. ATCRBS REPLIES PER REPORT: MODE S INTERROGATION RATE — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 3 of 3)

The Mode S interrogation rate for the en route sensor is about 20 percent higher than the terminal sensor when compared for all R/R, fruit rates, and types of aircraft tracks except zenith cone tracks. This was due to a software problem in release 6.3 which caused a high reinterrogation rate on the en route sensor front antenna face. The back antenna face interrogation rate correlated very closely with the terminal sensor. This software problem was not present in release 7.2. The large quantity of zenith cone interrogations per scan was caused by the sensor continuing to interrogate the aircraft, up to 40 times per scan, even though the aircraft had entered the zenith cone. This continued for six scans before the sensor deletes the aircraft from track status.

The surveillance tracker b/s ratio is presented in figure 8 for both sensors. These data represent the results of using simulated radar reports from ARIES to supplement the update of beacon tracks. For example, if no beacon reply was received from an aircraft in a particular scan, then a radar report could be substituted. The probability of a radar report being generated for an aircraft on any one scan was 0.80.

The b/s ratio for both ATCRBS and Mode S tracks was approximately 100 percent for both sensors operating at an R/R of 0.93 or greater (figures 8A and B) with one exception. The en route sensor for conflicting tracks at an R/R of 0.93 with no fruit (figure 8A) shows a b/s ratio of 94 percent. This low b/s ratio was due to one aircraft (1 of 23 aircraft tracks being averaged together for plotting comparison) having an association/correlation lockout problem in the en route sensor software. The particular aircraft is involved in an overtake conflict with a slower aircraft. At the point the two targets were garbled, the association/correlation lockout software prevented proper correlation and allowed a new track to be initiated. This new track appeared with the original tracks having the same ATCRBS Mode 3/A code as the overtaking aircraft. This problem, which occurred only one time, has been corrected in software release 7.2. Removing this one track from the en route sensor b/s statistics for conflict tracks would produce a b/s ratio of 99.9 for an R/R of 0.93 and no fruit. This is comparable to the terminal sensor.

The b/s ratio for Mode S tracks was approximately 100 percent for an R/R of 0.7 and high fruit rates (figure 8C). The b/s ratio for ATCRBS tracks under the high fruit rate and an R/R of 0.7 appear lower for the en route sensor than for the terminal sensor. This difference was due to the b/s ratio, derived from surveillance track information, being comprised of update data from both antenna faces at the en route sensor. Radar information was available only from the en route sensor front-face antenna. Therefore, radar data were available for substitution in surveillance track updating only for front-face targets without beacon reports. Back-face antenna targets without a beacon report were coasted and resulted in a lower b/s ratio at the en route sensor than at the terminal sensor for the low R/R and high fruit rates.

The benefit of using radar reports to supplement updating aircraft tracks is best seen by comparing the ATCRBS b/s ratio for an R/R of 0.70 (figure 8C) with the Pd for the same conditions (figure 4C). An increase of at least 5 percent is achieved for b/s as compared to Pd for both sensors due to the addition of the radar report update. The Mode S b/s ratio was approximately 100 percent for both sensors and was not significantly affected by fruit rate, R/R, or flight patterns.

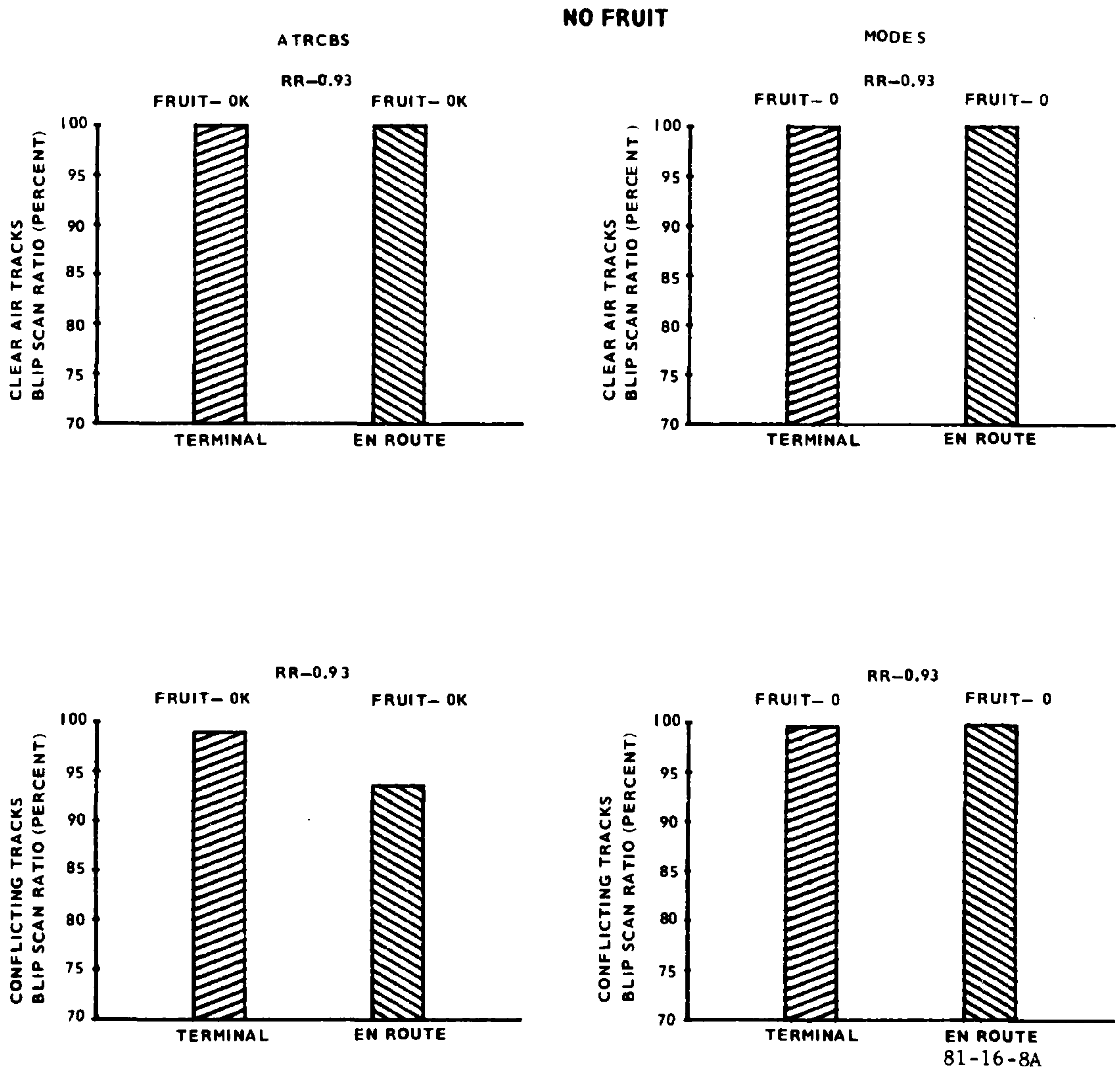


FIGURE 8. BLIP SCAN RATIO — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 1 of 3)

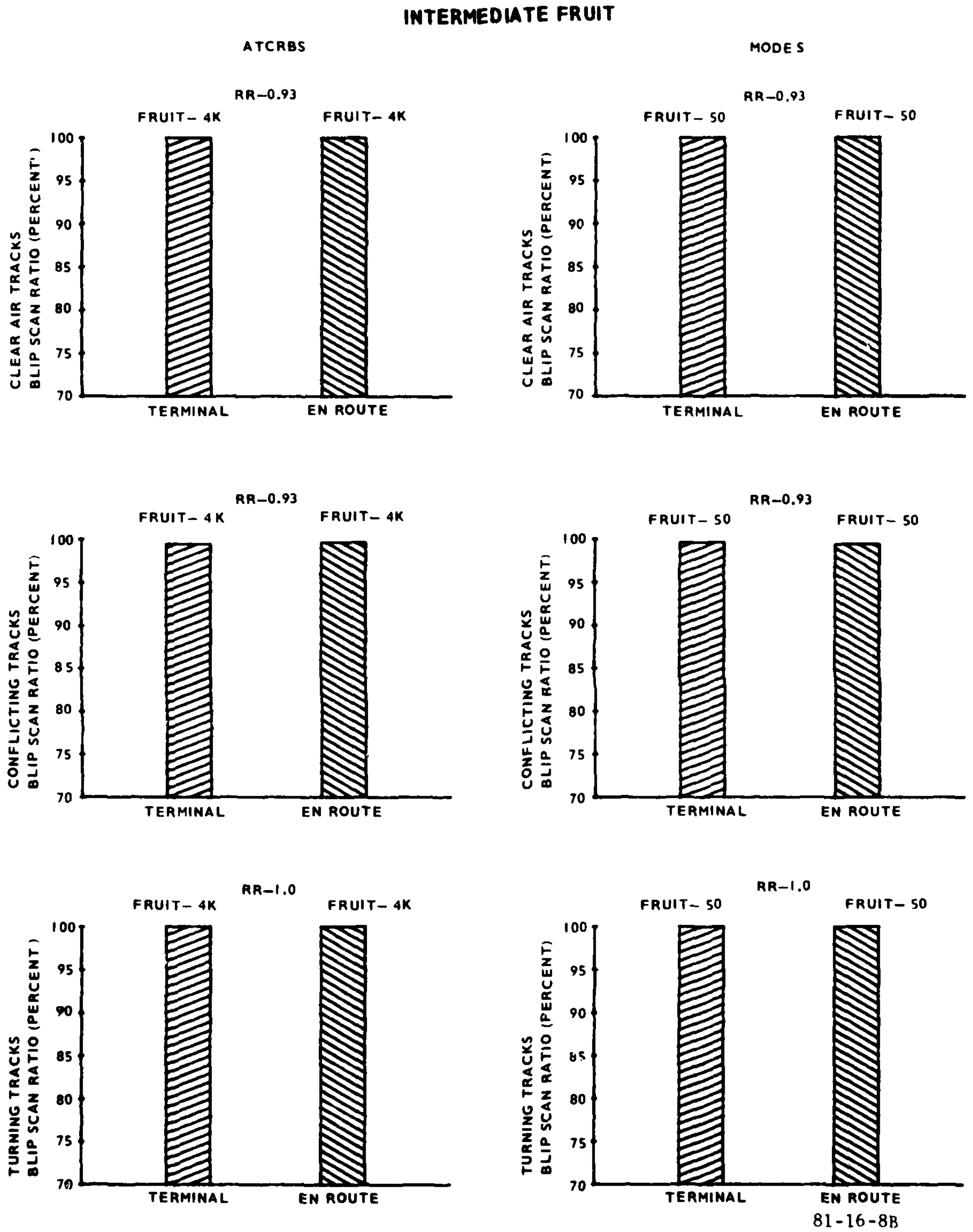


FIGURE 8. BLIP SCAN RATIO — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 2 of 3)

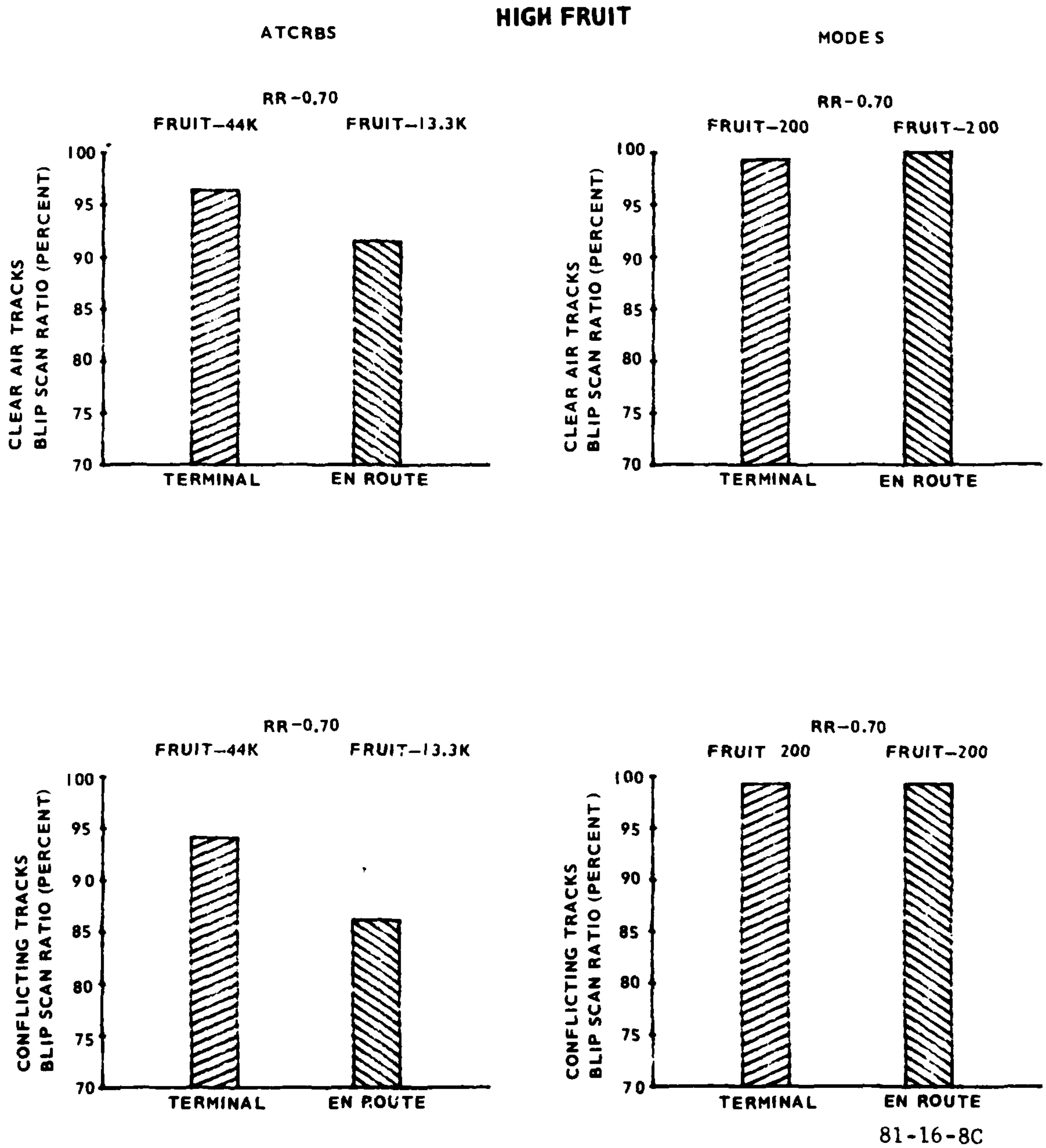


FIGURE 8. BLIP SCAN RATIO — TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE RECEIVE BEAM WIDTH 2.4° (Sheet 3 of 3)

PHASE II TEST RESULTS.

The results presented in this section delineate the surveillance characteristics of Mode S en route and terminal sensors operating with an effective receive beam width of 3.4° and software release 7.2. Although multisite software was used, each sensor was tested in a mode such that it functioned as though it were the only operational sensor. Modems from the sensor under test to adjacent sensors were disabled to prevent intersensor communications. Sensor fail messages were input to the sensor under test informing it that other sensors in the network had failed. As a result, the data presented herein represents the sensors operating in a single, unnetted configuration using multisite software.

The data are presented in graph form to depict the surveillance characteristics of: (1) the terminal sensor as a function of signal strength, (2) the terminal sensor for narrow and wide beam width operation, and (3) the terminal sensor to en route sensor in wide beam width operation.

The environment simulated during Phase II testing is summarized below:

	Aircraft Track Type		
	Clear, Conflict, Zenith Cone	Turning	Signal Strength
Round Reliability (R/R)	0.70 and 0.93	0.7 and 1.0	0.93
Generated Fruit			
ATCRBS	0; 4,000; 44,000/13,300	0; 4,000; 44,000/13,300	0 and 44,000
Mode S	0; 50; 200	0; 50; 200	0 and 200
Radar Probability	0.80	0.80	none

It is to be noted that to insure the ER requirement of 8 fruit per sweep would not be exceeded, the maximum ATCRBS fruit rate was set at 44,000 replies per second for the terminal sensor (60 nmi) and 13,300 replies per second for the en route sensor (200 nmi).

PERFORMANCE AS A FUNCTION OF SIGNAL STRENGTH (TERMINAL SENSOR). The scenarios used to test the terminal sensor as a function of signal strength, utilized 20 simulated targets flying orbits (constant range) and four stationary targets that were used by DR&A programs for synchronization. The orbiting targets started in groups of ten at an azimuth of 90° evenly spaced in range from 7 to 100 nmi, and flew counter-clockwise orbits. Each aircraft had its RF power level input to the sensor adjusted as a function of its range from the sensor. Two of the test scenarios simulated ATCRBS targets with fruit rates of 0 and 44,000 replies per second and two simulated Mode S targets with fruit rates of 0 and 200 replies per second.

After analyzing data from these tests, plots were formulated to depict sensor operation as a function of signal strength. Each of the selected performance parameters is discussed in the following paragraphs. The data plotted in figure 9 depict ATCRBS targets in an ATCRBS fruit environment on the left side and Mode S targets with Mode S fruit on the right side. The results reported herein are quite similar to those obtained previously for an effective receive beam width of 2.4° and documented in FAA report No. FAA-NA-79-52. Comments will be made on any significant differences.

The Pd of ATCRBS targets in a fruit environment of 0 and 44,000 replies per second maintained 100 percent detection for signal strengths decreasing to -76 decibels relative to 1 milliwatt (dBm). A 90 percent detection was achieved at -79 dBm for 0 fruit. Detection drops to 0 at -81 dBm. These values agree within 1 dB of the data obtained for Pd under effective beam width of 2.4°.

The Pd of Mode S targets in a fruit environment of 0 and 200 replies per second maintained 100 percent detection for signal strengths down to -78 dBm. A 90 percent detection was achieved at -79 dBm for 0 fruit. Detection decreases to 0 at -81 dBm. This is approximately 1 dB more sensitive than reported for an effective receive beam width of 2.4°.

An ATCRBS Mode 3/A code reliability of 100 percent was maintained for signal strengths down to -75 dBm and -72 dBm for fruit rates of 0 and 44,000 replies per second, respectively. A reliability of 0 was achieved at signal strength of -80 dBm for both fruit rates. The zero value agrees within 1 dB of the data obtained for 2.4° effective receive beam width. The signal strength for 100 percent reliability was about 3 dB more sensitive at 2.4° effective receive beam width than for the 3.4°. This reduction in Mode 3/A code reliability was due to a software change incorporated during 3.4° effective receive beam width testing, which delayed report-to-track correlation in an attempt to improve the capacity of the DABS sensor throughput. This problem will be discussed in further detail in later sections.

The sensor maintained a Mode S ID and Mode C reliability of 100 percent for signal strengths down to -79 dBm and reached 0 percent at -81 dBm. These values are approximately 1 dB more sensitive than reported for 2.4° effective receive beam width.

The ATCRBS Mode C reliability was 90 percent or better for signal strengths down to -77 dBm and -75 dBm for fruit rates of 0 and 44,000 replies per second, respectively. This represents an improvement of approximately 3 to 4 dB over that obtained with 2.4° effective receive beam width. The improvement is due to the additional replies caused by increasing the effective receive beam width.

The sensor maintained an ATCRBS replies per report rate of 5 or greater for input signal strengths down to -76 dBm for 0 fruit. This cutoff point is the same as for 2.4° effective receive beam width testing, although the maximum replies were limited to 4 replies per beam dwell instead of the 5.6 available with 3.4° effective receive beam width.

The Mode S interrogation rate was approximately 1.1 for signal strengths down to -77 dBm, and then increased sharply to about 3 interrogations per scan at a signal strength of -80 dBm and -79 dBm for fruit rates of 0 and 200 replies per second,

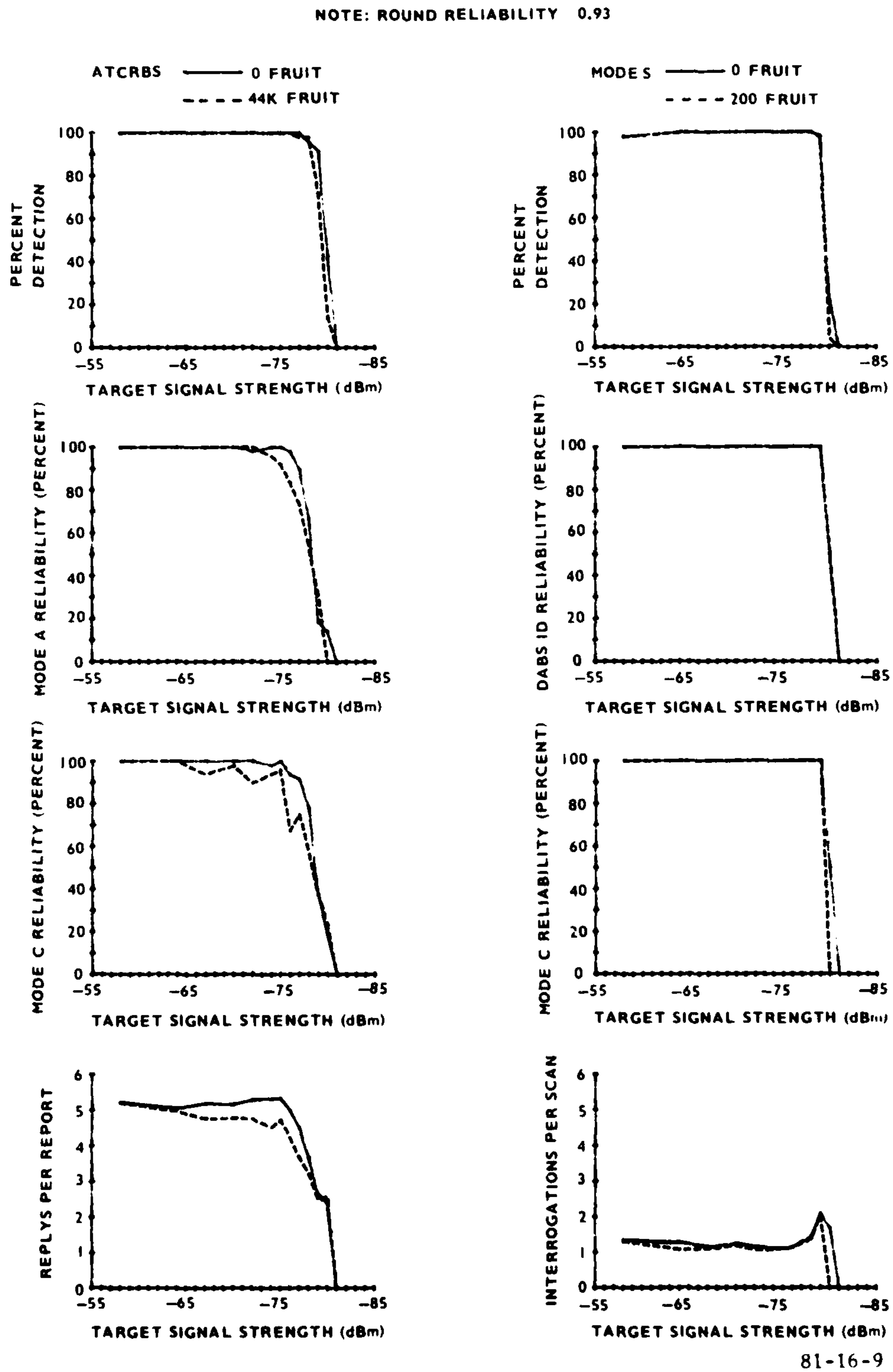


FIGURE 9. ATCRBS/MODE S PERFORMANCE AS A FUNCTION OF SIGNAL STRENGTH

respectively. The response is very similar to that obtained for the 2.4° beam width testing, except that the interrogation rate is about 10 percent lower and the sensitivity is about 1 dB greater for the 3.4° effective receive beam width results. These changes are due to the increased effective receive beam width inceasing the possibility of receiving a valid reply further away from the antenna boresight. In both beam width tests, interrogations were transmitted as much as 45 azimuth units (0.99°) before tracker predicted azimuth of the target. Therefore, replies to these early azimuth interrogations were more likely to be detected using the 3.4° than the 2.4° effective receive beam width.

TERMINAL SENSOR PERFORMANCE FOR EFFECTIVE RECEIVE BEAM WIDTHS OF 2.4° AND 3.4°. The data utilized in this section for an effective receive beam width of 2.4° has been previously documented in report No. FAA-NA-79-52. The Mode S simulated track data presented therein indicated values from 99 to 100 percent for performance measures of Pd, ID reliability, altitude code reliability, and b/s ratio. The results of performing the same tests with an effective receive beam width of 3.4° indicated no significant change of performance at all R/R, fruit rates, and aircraft flight patterns. Therefore, graphical presentations of these data are not made. The data for Mode S interrogation rate, however, did reflect a change and will be presented later in this section. The graphs in figures 10 through 15 compare the Mode S terminal sensor performance for ATCRBS targets for the two values of beam width tested.

Results for Pd, presented in figure 10 for ATCRBS targets, indicate no degradation occurred by increasing the effective receive beam width. The plot for an R/R of 0.7 shows an increase in Pd of about 7 percent by utilizing the wide beam. This increase is due to the increased number of replies available in the wide beam to generate a report.

The Mode 3/A code reliability for ATCRBS targets are shown in figure 11 for both beam widths. For no fruit, the Mode 3/A code reliability data are in close agreement for wide beam width and narrow beam width testing. As the fruit increases, the wide beam width Mode 3/A code reliability decreases more rapidly than that achieved with the narrow beam width. This apparent degradation is a result of software differences between software release 6.3 and 7.2.

The software release 6.3, used during the narrow beam width testing, employed report-to-track correlation to upgrade low confidence Mode 3/A code data. This upgrading, based upon the track history stored within the Mode S surveillance processor, was performed prior to target report dissemination to ATC users. Therefore, the same upgraded Mode 3/A data was disseminated to correlating (SSF) and noncorrelating (TATF) users.

Software release 7.2, used during wide beam testing, also used the report-to-track correlation for all target reports disseminated to noncorrelating users (TATF). However, in an attempt to improve the capacity of the Mode S sensor throughput, target reports were disseminated to correlating users (SSF) prior to report-to-track correlation. As a result, many targets mixed within high fruit or conflicting situations were disseminated to the correlating user (SSF) prior to report-to-track correlation being performed. Accordingly, the low confidence Mode 3/A code data of these reports were not upgraded by the Mode S surveillance processor.

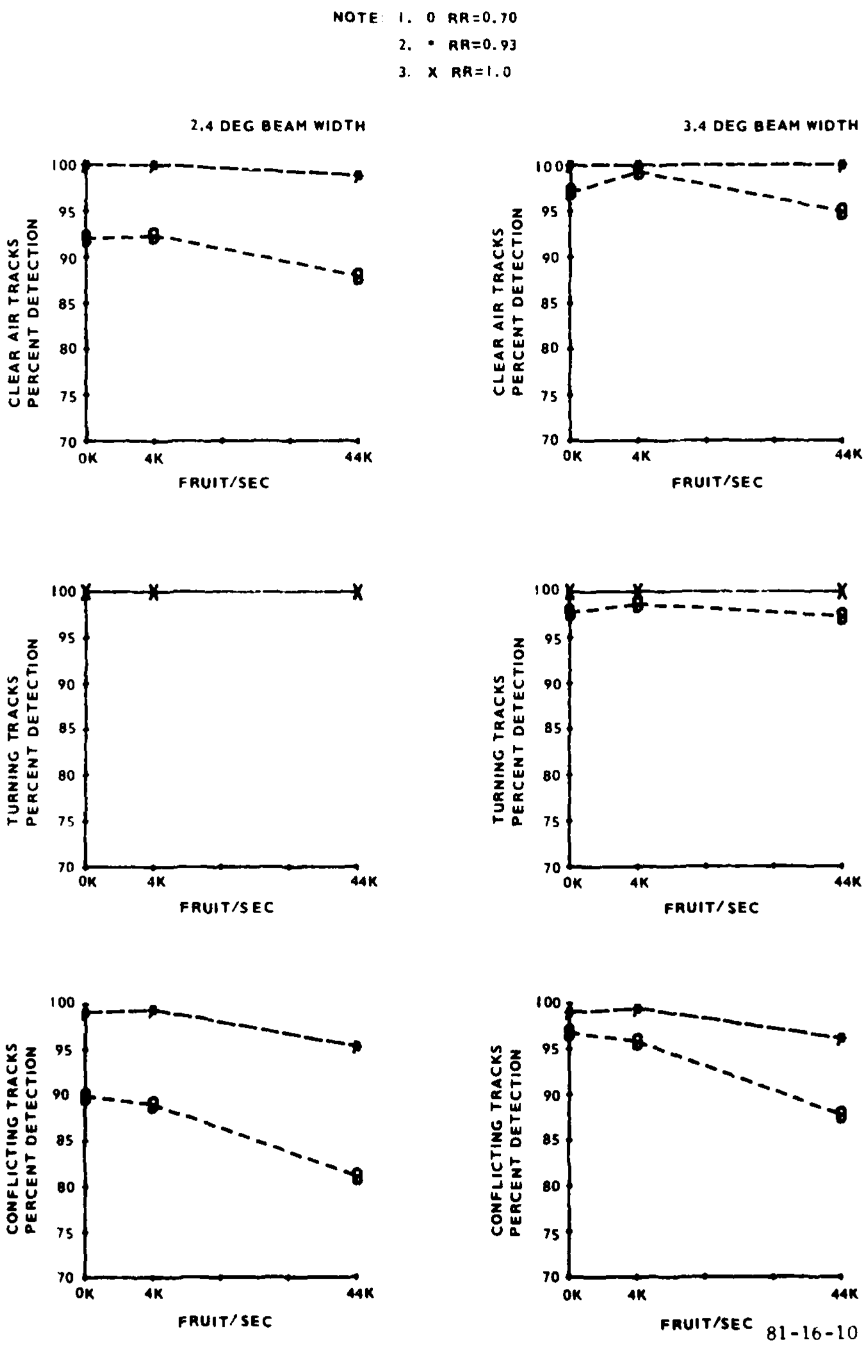


FIGURE 10. PERCENT DETECTION (ATCRBS) TERMINAL SENSOR, EFFECTIVE BEAM WIDTH 2.4° VERSUS 3.4°

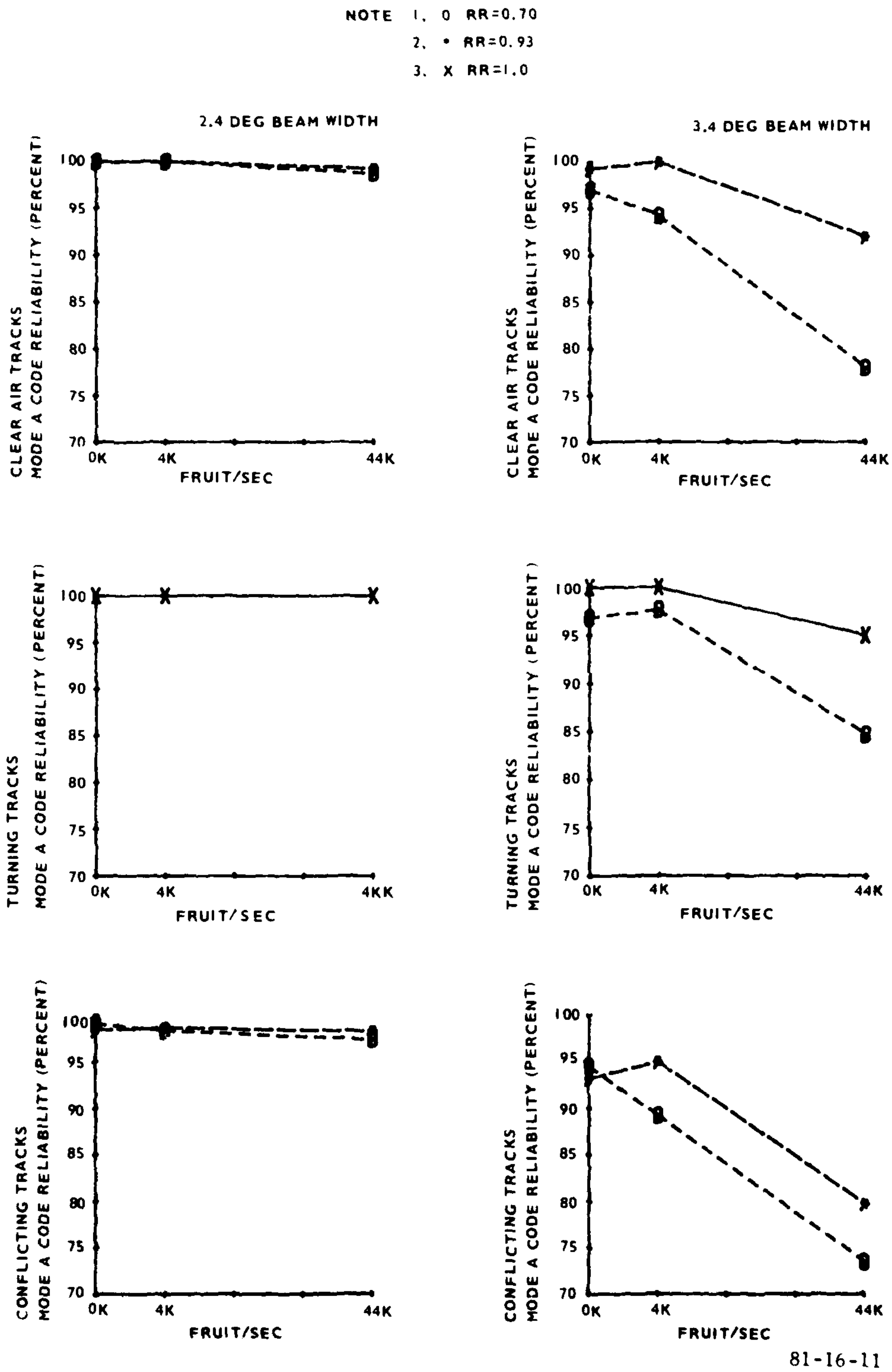


FIGURE 11. MODE 3/A CODE RELIABILITY (ATCRBS) TERMINAL SENSOR, EFFECTIVE BEAM WIDTH 2.4° VERSUS 3.4°

The DR&A programs were designed to analyze only the data being disseminated to correlating users (SSF). As such, the low Mode 3/A reliability phenomena experienced during the wide beam width testing caused the sensor performance to appear to become severly degraded.

A special DR&A program was assembled to analyze the noncorrelating user (TATF) disseminated data for the wide beam width, R/R of 0.7, and 44,000 replies per second fruit rate data. The comparative DR&A results for correlating and noncorrelating users are tabulated in table 3.

TABLE 3. COMPARISON OF RELEASE 7.2 DISSEMINATED DATA TO CORRELATING AND NONCORRELATING USERS

(3.4° Beam Width, R/R = 0.7, Fruit Rate = 44,000 Replies Per Second)

	Clear Air Tracks			Conflicting Tracks		
DR&A Data Analyzed	Pd (%)	Mode 3/A Rel (%)	Alt Rel (%)	Pd (%)	Mode 3/A Rel (%)	Alt Rel (%)
Correlating User (SSF)	94.9	78.0	83.0	86.4	74.4	76.1
Noncorrelating User (TATF)	94.9	99.3	83.0	86.4	96.7	76.1
Difference	0	+21.3	0	0	+22.3	0

In summary, table 3 indicates that for this extreme case of low R/R of 0.7 and high fruit rate, data disseminated to noncorrelating users (TATF) represents a higher Mode 3/A code reliability than that disseminated to correlating users (SSF).

The sensor performance parameters of Pd and altitude code reliability are unaffected by the dissemination and correlation problem cited above.

A comparison of ATCRBS altitude code reliability for both beam widths at the terminal sensor is presented in figure 12. The altitude code reliability is improved from 3 to 10 percent when using wide beam as compared to narrow beam. Improvement is seen for all values of R/R, aircraft tracks, and fruit rates.

Test results for ATCRBS replies per report are shown in figure 13 for narrow and wide beam width. Due to the increase in beam width from 2.4° to 3.4°, the maximum replies that could be expected in a beam dwell would increase from 4.0 to 5.6, or a 40 percent increase for ATCRBS targets with an R/R of 1.0. The corresponding data shown in figure 13 reveals that the replies per report have increased as expected for all R/R, aircraft tracks, and fruit rates of 0 and 4,000 replies per second. The replies per report for high fruit rate of 44,000 replies per second also increased when the beam was opened to 3.4°.

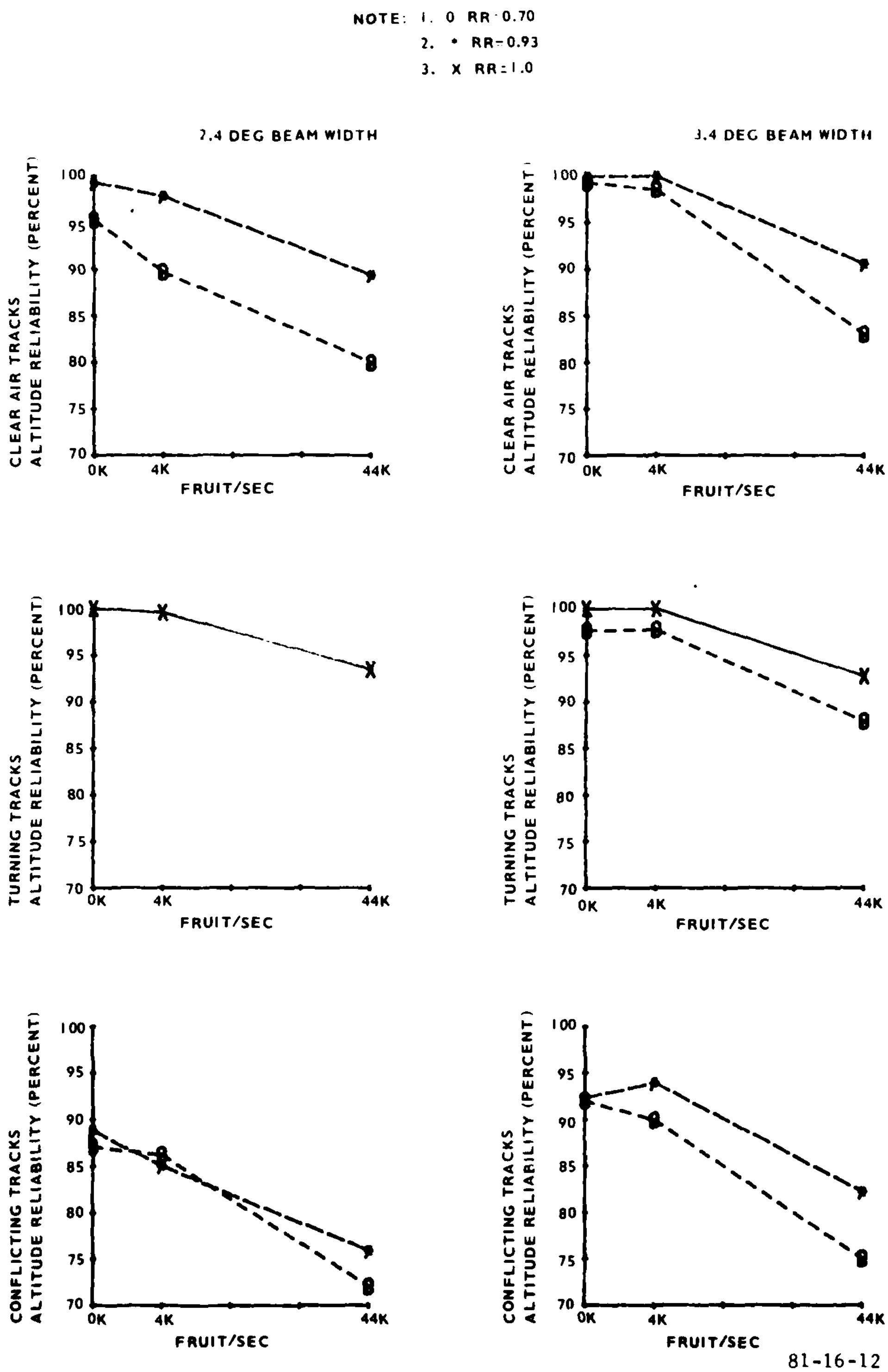


FIGURE 12. ALTITUDE RELIABILITY (ATCRBS) TERMINAL SENSOR, EFFECTIVE BEAM WIDTH 2.4° VERSUS 3.4°

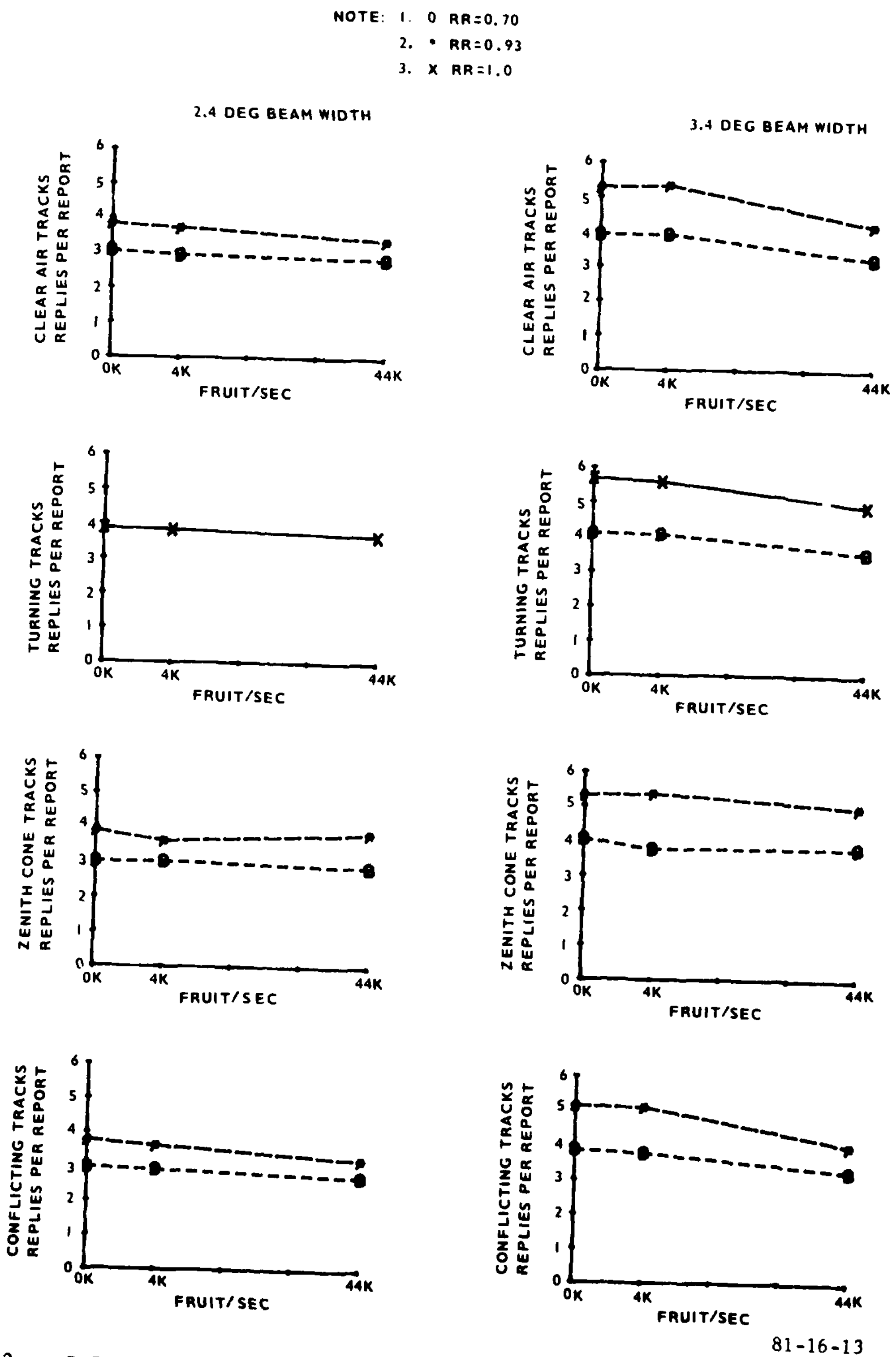


FIGURE 13. REPLIES PER REPORT (ATCRBS) TERMINAL SENSOR, EFFECTIVE BEAM WIDTH 2.4° VERSUS 3.4°

The interrogation rate for Mode S targets, as seen by the terminal sensor using both beam widths are presented in figure 14. For R/R, fruit rates, and aircraft tracks tested, the majority of the interrogation rates decreased when the beam width increased. Reduction in interrogation rates as much as 18 percent was realized for turning tracks at an R/R of 1.0. The majority of the reductions were in the range of 5 to 10 percent.

The Mode S roll-call earliest interrogation azimuth remained at 45 azimuth units (0.99°) off-boresight for narrow and wide beam width testing. At this 0.99° offset from boresight, the round reliability of the system would be greater for wide beam width than for narrow beam width testing. As a result, the interrogation rate for Mode S aircraft would be expected to decrease for wide beam width testing as compared to narrow beam width testing.

The b/s ratio for the terminal sensor surveillance tracks is presented in figure 15 for ATCRBS targets and both beam widths. No significant change was observed for R/R of 0.93 or greater, all fruit rates, and aircraft tracks. An increase of approximately 2 percent in b/s ratio was observed due to the increased beam width at an R/R of 0.7 and is independent of fruit rates and aircraft tracks.

TERMINAL VERSUS EN ROUTE SENSOR PERFORMANCE AT AN EFFECTIVE RECEIVE BEAM WIDTH OF 3.4°. A comparison of the surveillance characteristics for the terminal and en route sensors operating at an effective receive beam width of 3.4° are presented in this section. The sensors' surveillance performance parameters are plotted as a function of fruit rates in figure 16 through 25 for ATCRBS and Mode S targets. In each figure the terminal sensor is plotted on the left and the en route sensor on the right side of the figures.

The Pd results for both sensors are presented in figure 16 for Mode S and in figure 17 for ATCRBS targets. The Mode S target performance for Pd is between 99 and 100 percent for both sensors with no discernible effect being introduced by Mode S fruit. The ATCRBS target Pd (figure 17) was 95 percent or better at both sensors for the three types of tracks, R/R, and low fruit rates tested. At the high fruit rates the Pd decreased more rapidly at the en route sensor than at the terminal sensor.

Examination of test data disclosed the cause to be associated with the en route sensor front/back antenna operation for target that are separated in azimuth by 180°. The en route sensor did not always generate a report for targets in this orientation even though the ARIES was responding with as many as six ATCRBS replies for the targets on each antenna face. As soon as the targets in question would move so that this 180° orientation conflict was eliminated, beacon reports would again be properly generated for the targets. Eliminating targets from the Pd statistics in which this 180° conflict occurred would have increased the Pd of the en route sensor to values equal to those of the terminal sensor.

It is suspected that the front/back antenna problem at the en route sensor is caused by a software problem in software release 7.2. The Mode 3/A and altitude reliability, discussed later in this report, were not influenced by this anomaly because their values are based upon the ratio of the number of times a target was detected with the correct code to the number of times the target was detected. It should be noted that the Pd for the en route sensor at high fruit and an R/R of 0.7 for 3.4° beam width (figure 17) is the same as that reported for 2.4° beam width

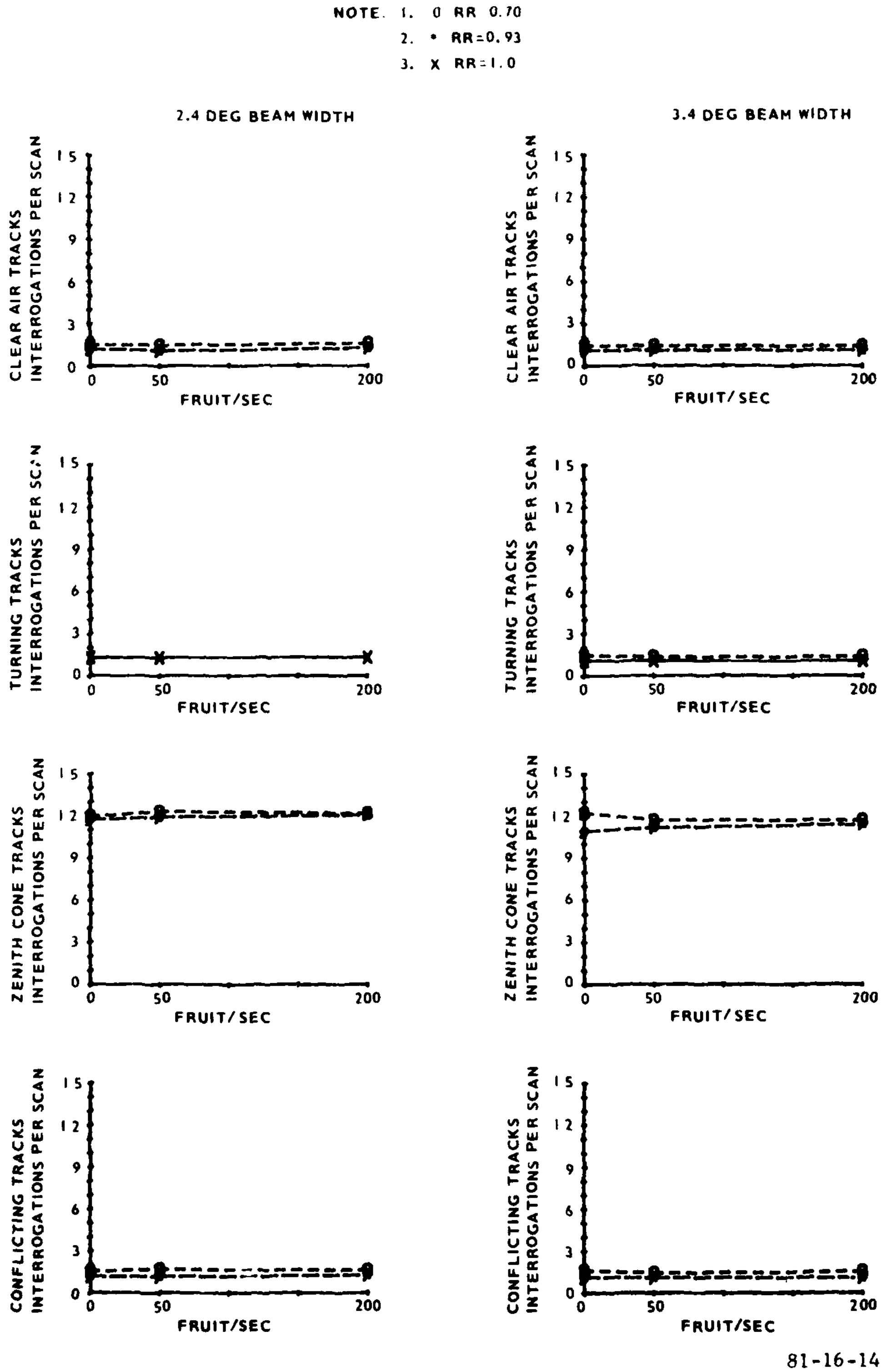


FIGURE 14. INTERROGATION RATE (MODE S) TERMINAL SENSOR, EFFECTIVE BEAM WIDTH 2.4° VERSUS 3.4°

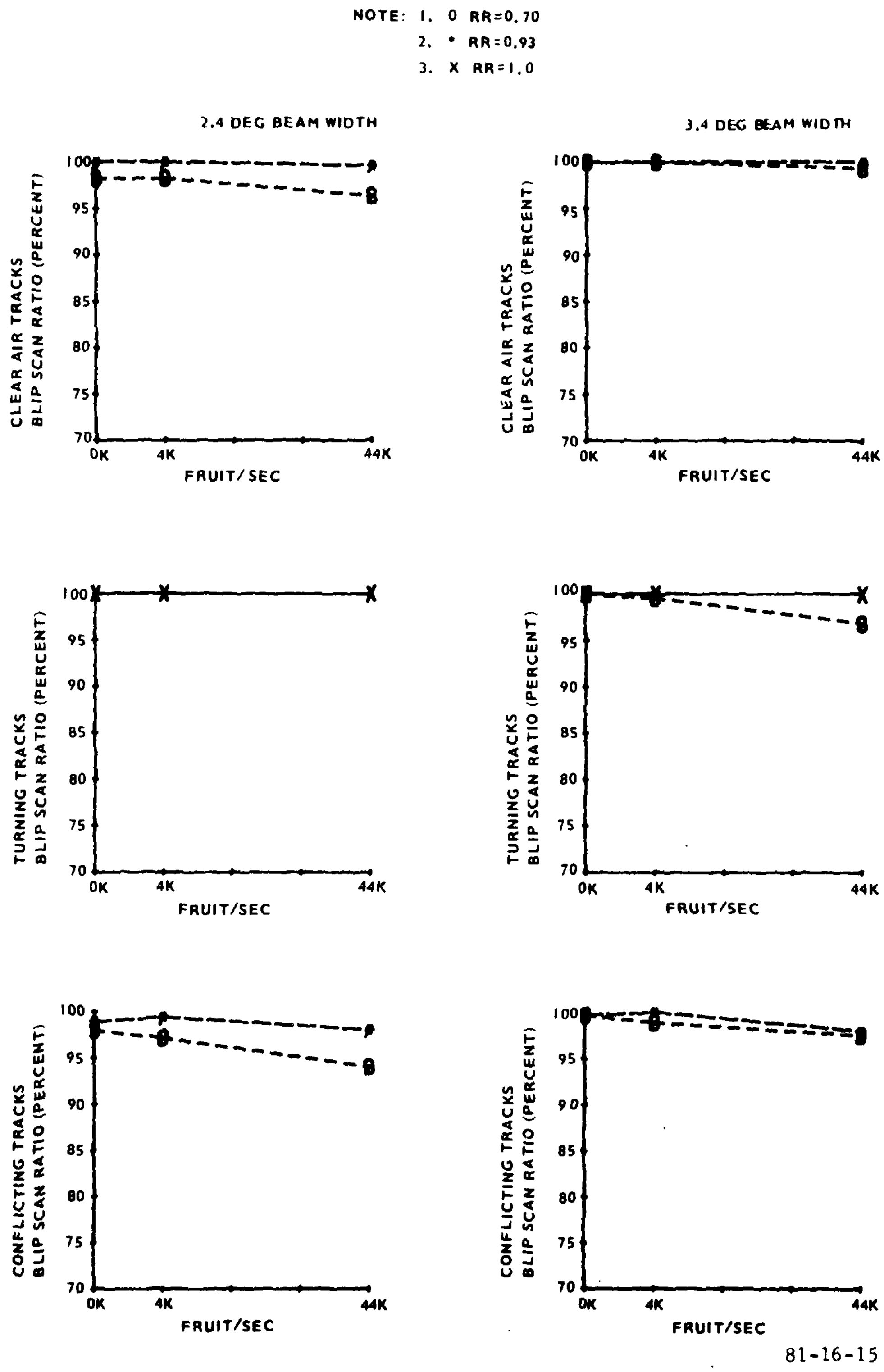


FIGURE 15. BLIP SCAN RATIO (ATCRBS) TERMINAL SENSOR, EFFECTIVE BEAM WIDTH 2.4° VERSUS 3.4°

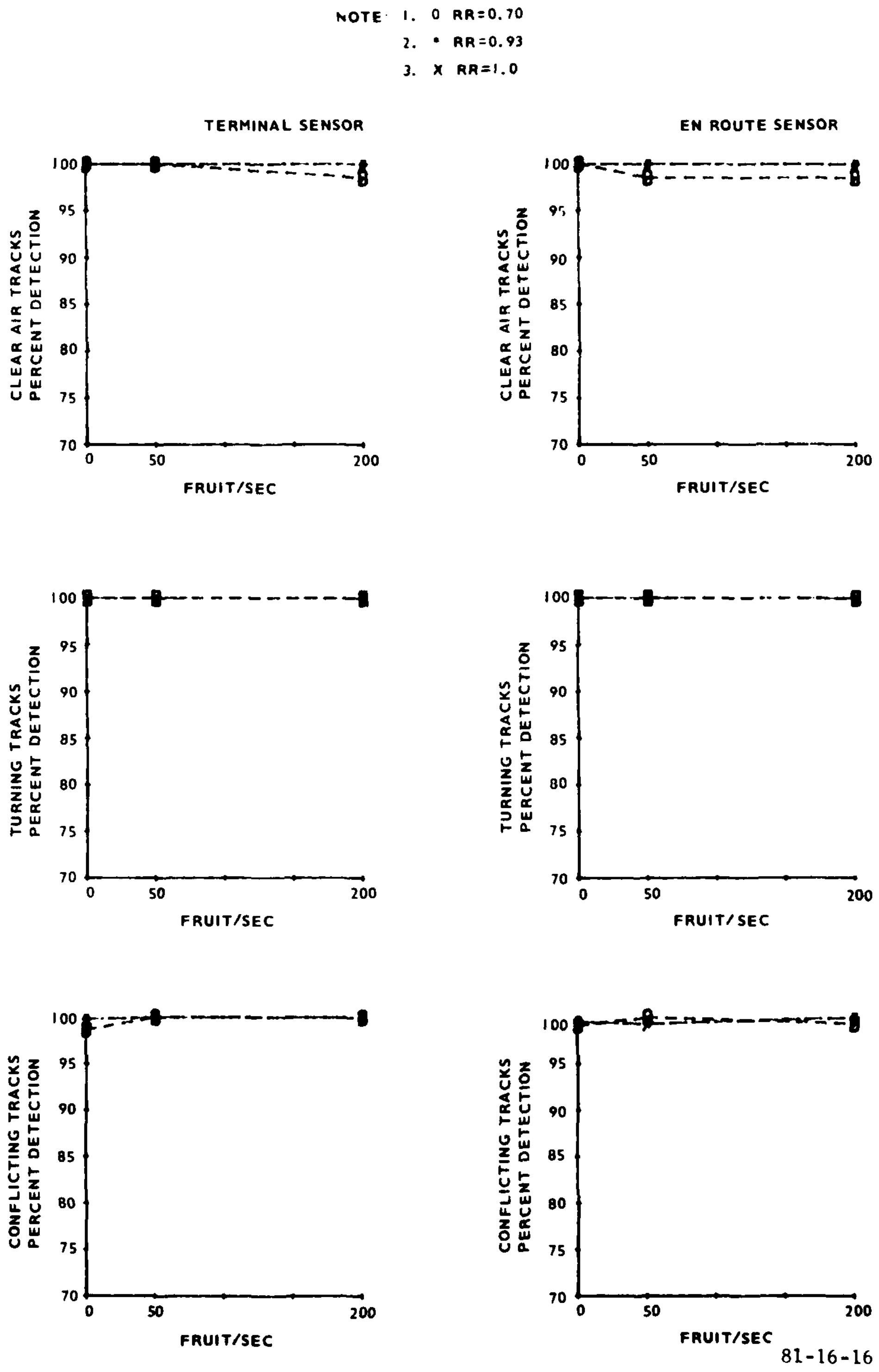


FIGURE 16. PERCENT DETECTION (MODE S) TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE BEAM WIDTH 3.4°

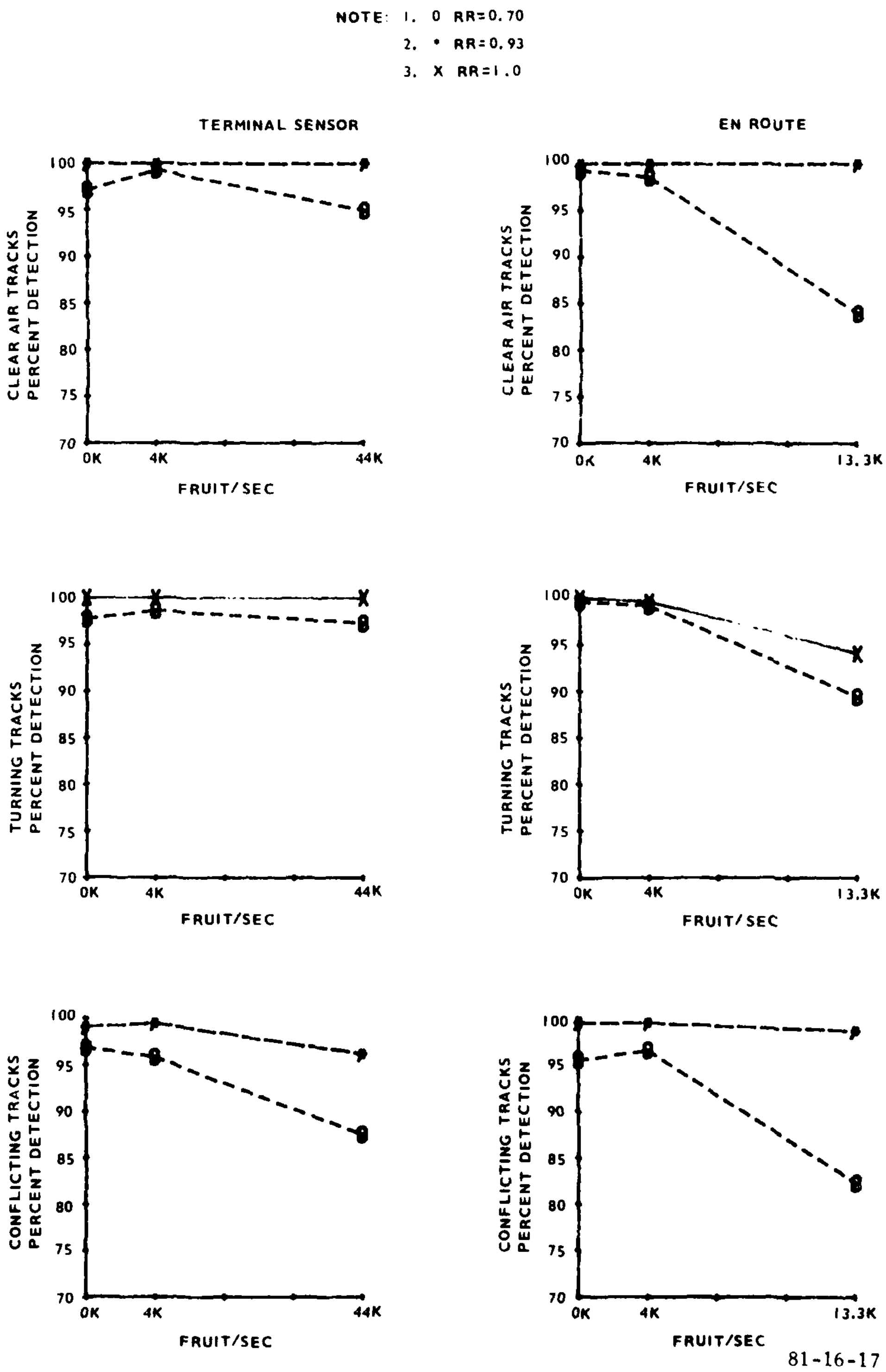


FIGURE 17. PERCENT DETECTION (ATCRBS) TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE BEAM WIDTH 3.4°

(figure 4C). The improvement (5 to 8 percent) realized by widening the beam width at the terminal sensor was not seen at the en route sensor.

The ID reliability (Mode S) and Mode 3/A code reliability (ATCRBS) are presented in figures 18 and 19, respectively. For Mode S targets, the ID reliability remained at 100 percent for both sensors throughout the test variables.

The Mode 3/A code reliability plotted in figure 19 for ATCRBS targets remained relatively constant for a given type of aircraft track at both sensors, except at the maximum fruit rate. As noted before, the maximum ATCRBS fruit rate was set at 44,000 replies per second for the terminal sensor (60 nmi range) and at 13,300 for the en route sensor (200 nmi range) to insure the ER requirement of 8 fruit per sweep would be tested and not exceeded. This requirement results in a denser fruit environment for the terminal sensor than for the en route sensor. Since the same scenario aircraft load was tested at each sensor, the probability of fruit garbling with valid target replies is approximately one-third as great at the en route sensor as at the terminal sensor. Therefore, the fruit environment can be expected to have a smaller impact upon the performance of the en route sensor than the terminal sensor.

Also, the phenomena previously discussed for the terminal sensor, low Mode 3/A code reliability, is a factor in the terminal response of figure 19. Briefly restated, the software release 7.2 delayed report-to-track correlation in an attempt to improve capacity of the sensor throughput. As a result, many of the targets in high fruit environments or in conflict situations were disseminated to the correlating users prior to target-to-track correlation. The DR&A program was designed to analyze only the data disseminated to the correlating users. As was demonstrated previously, DR&A of the disseminated noncorrelating users (TATF) data presents a Mode 3/A code reliability in excess of 95 percent.

Altitude reliability for both sensors is compared in figure 20 for Mode S and figure 21 for the ATCRBS targets. There was no appreciable deviation of the altitude code reliability from 100 percent throughout the test for Mode S targets. For ATCRBS targets, the altitude code reliability was in agreement for both sensors for all tests conditions, except the high fruit rate with the terminal sensor. At this combination of tests, the terminal sensor was indicating an altitude reliability between 6 and 18 percent lower than the en route sensor. For all other conditions agreement was within a few percent of each sensor. The difference in density of fruit at both sensors, as discussed previously under Mode 3/A code reliability, is the reason for the altitude code reliability differences in figure 21.

The results for Mode S interrogation rates are presented in figure 22 for both sensors. The two sensors have very comparable interrogation rates for targets having turning and conflicting tracks. For clear air tracks, however, the interrogation rates of the en route sensor are approximately 20 percent higher that that of the terminal sensor. This difference does not appear to be influenced by R/R or Mode S fruit rates, but, rather, as a function of the type of tracks being processed.

Investigation of this phenomena disclosed the cause to be associated with the channel management function of selecting the correct antenna face when two Mode S targets are separated in azimuth by 180°. The test scenario simulates four of the five clear air targets by flying outbound radials, each separated in azimuth

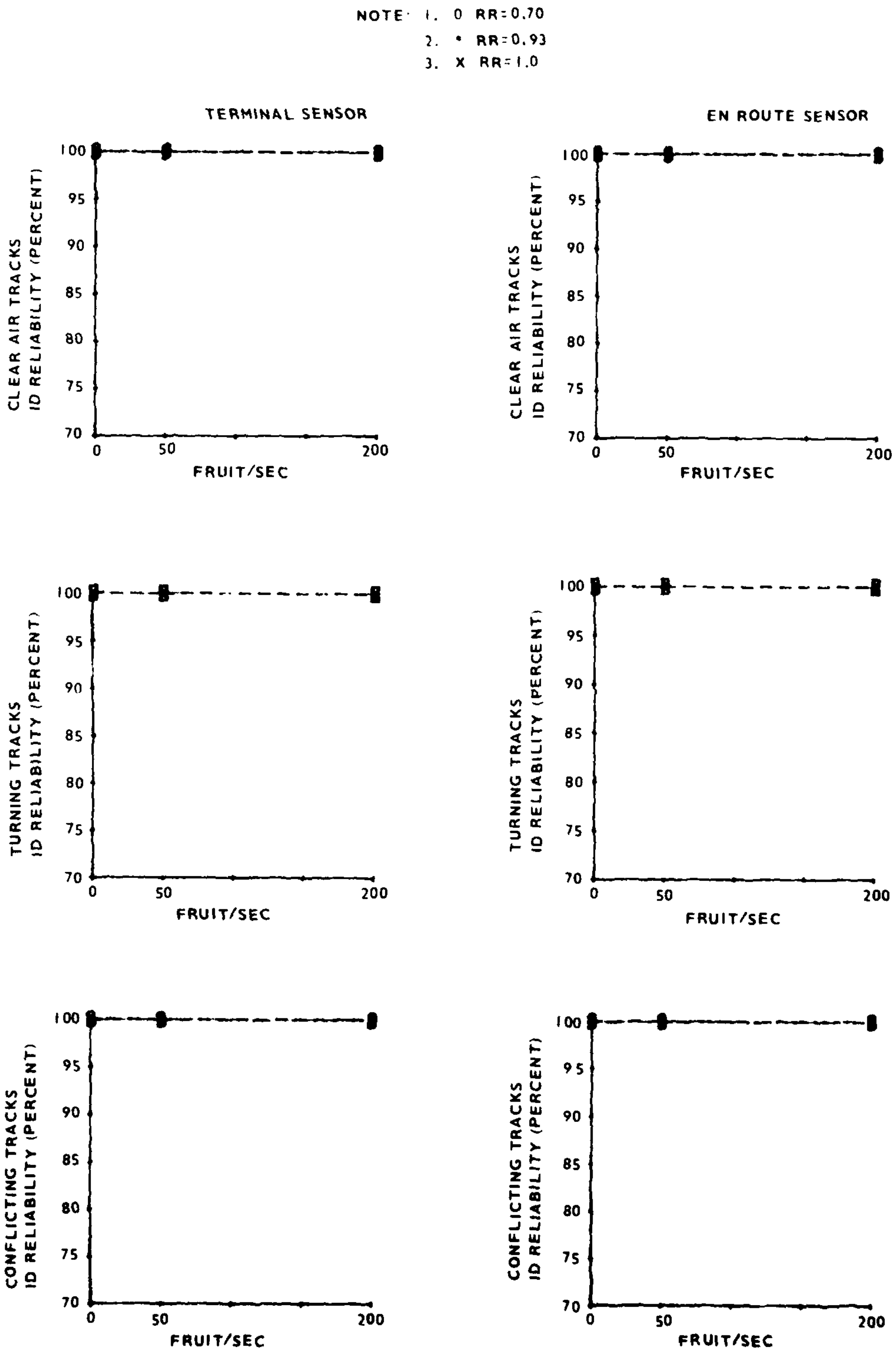


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FIGURE 18. ID RELIABILITY (MODE S) TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE BEAM WIDTH 3.4°

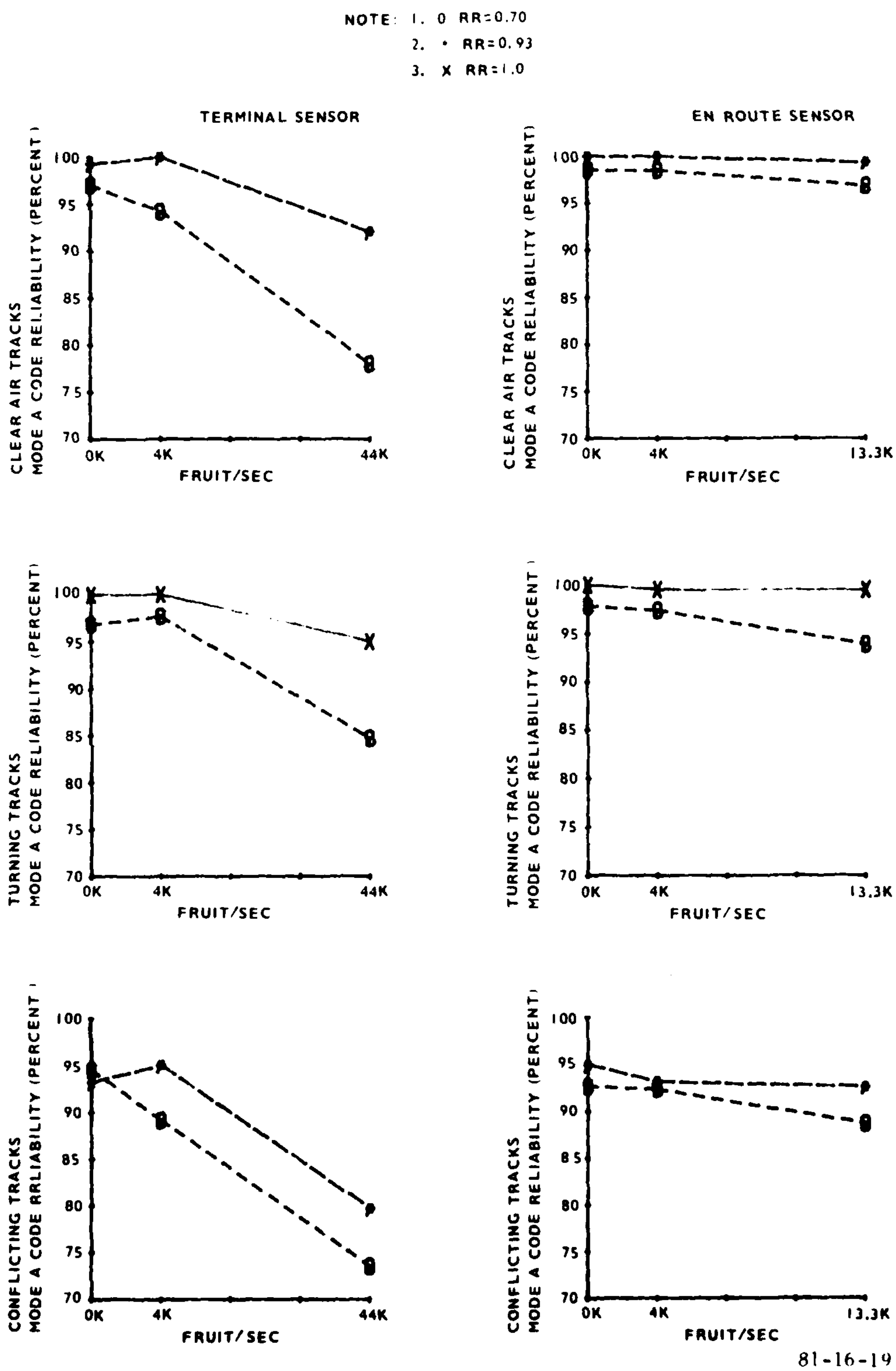

FIGURE 19. MODE 3/A CODE RELIABILITY (ATCRBS) TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE BEAM WIDTH 3.4°

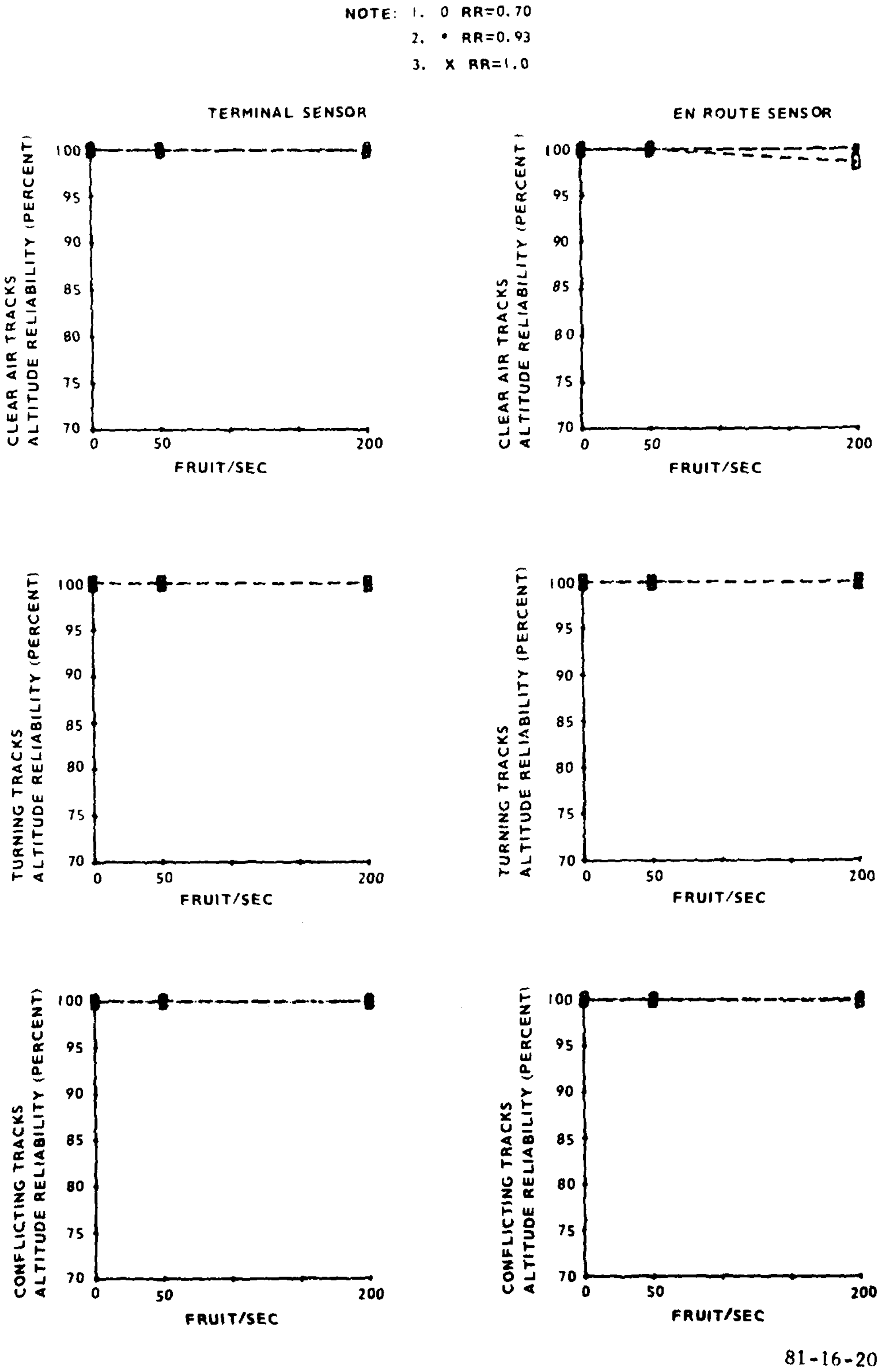

FIGURE 20. ALTITUDE RELIABILITY (MODE S) TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE BEAM WIDTH 3.4°

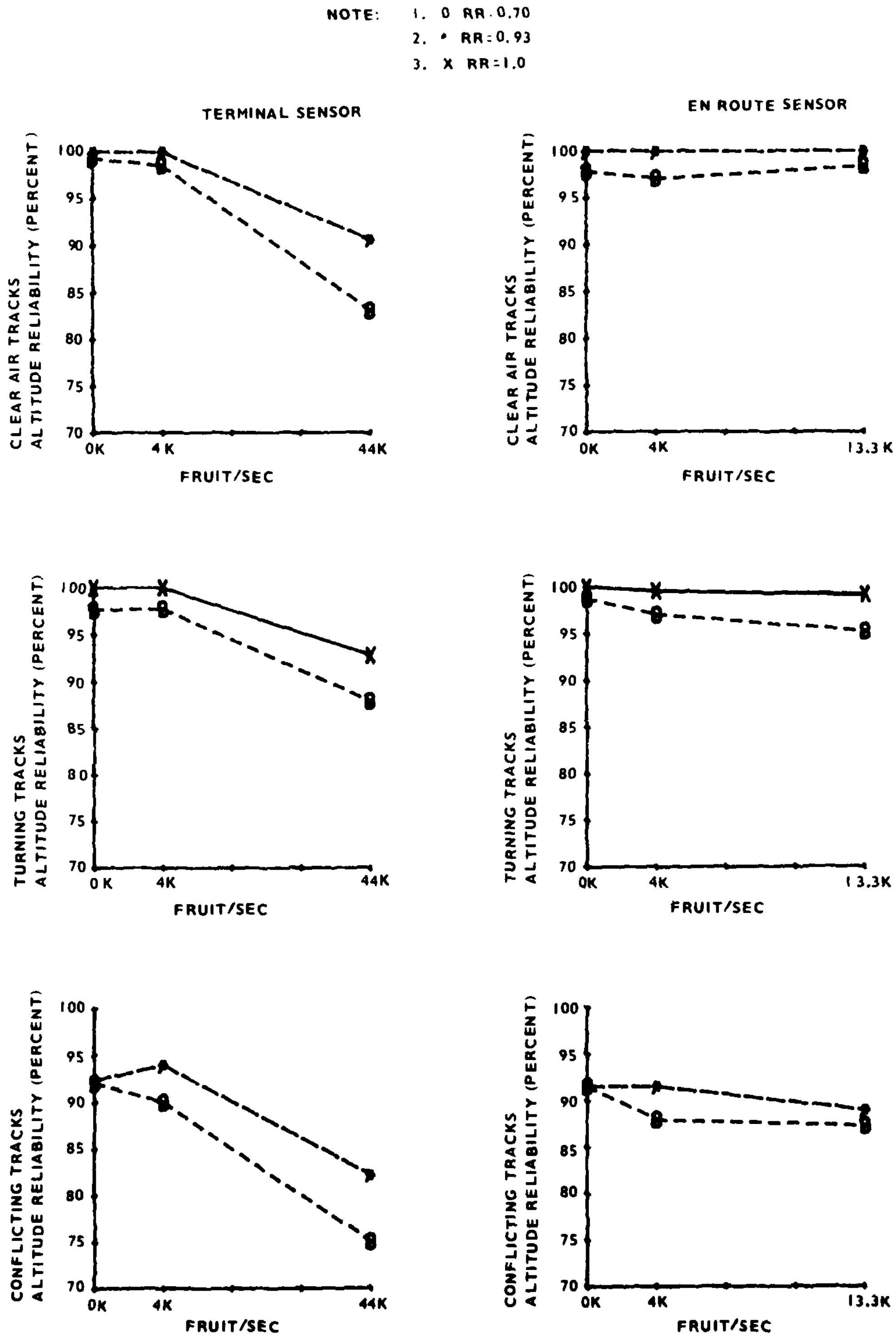

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FIGURE 21. ALTITUDE RELIABILITY (ATCRBS) TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE BEAM WIDTH 3.4°

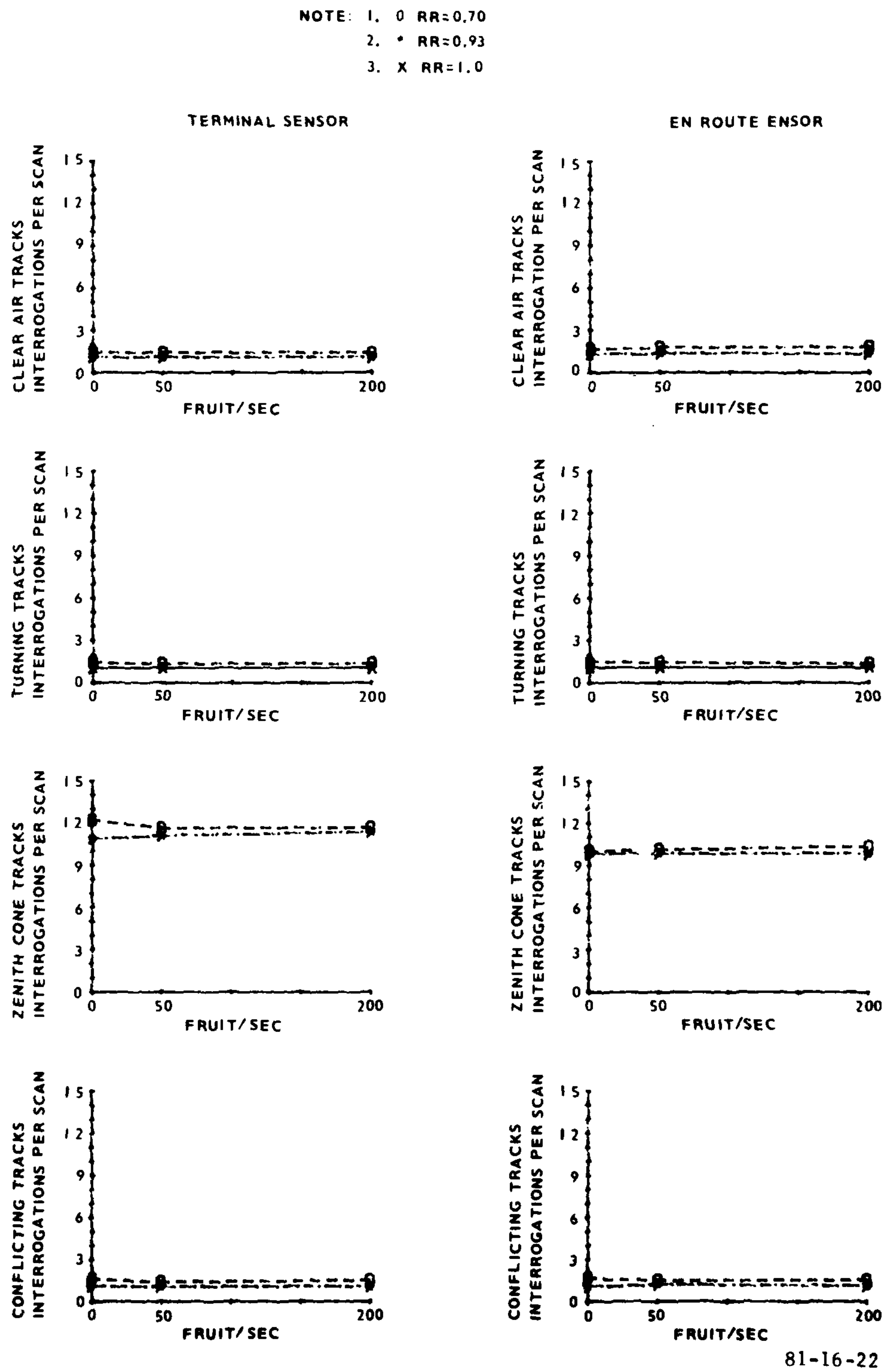

FIGURE 22. INTERROGATION RATE (MODE S) TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE BEAM WIDTH 3.4°

by 90°. Therefore, two aircraft pairs are in a constant azimuth separation of 180° which aggravated the situation, resulting in high reinterrogation rates. The fifth, nonradial, clear-air target did not experience this high reinterrogation rate.

This high reinterrogation rate for targets separated by 180° was not apparent when the en route sensor was retested under subsequent software releases. The exact cause of the problem is still under investigation.

The ATCRBS replies per report are compared in figure 23 for both sensors. The en route sensor maintains a nearly constant reply per report rate for all target types, R/R, and fruit rates tested. The reduction seen for R/R of 0.7 is due to the reduced number of replies available at the lower R/R. The replies per report for the terminal sensor are in close agreement with the en route sensor for all conditions except for the high fruit rate of 44,000 replies per second. The replies per report decrease slightly as a function of increased fruit rate for all target types and R/R tested.

The surveillance b/s ratio of both sensors is compared in figure 24 for Mode S and in figure 25 for ATCRBS targets. No appreciable difference in performance was observed for the Mode S targets. The b/s ratio for ATCRBS clear air and turning tracks (figure 25) is lower at the en route sensor than at the terminal sensor for high fruit rates and an R/R of 0.7. The reasons for this reduction has already been discussed under the anlaysis of Pd data for figure 17.

The en route sensor b/s ratio for conflicting track were approximately 25 percent lower than that for the terminal sensor. Determination of b/s ratio requires updating of the surveillance file with either beacon or radar reports. The en route sensor was providing reports for the conflicting targets, but a large quantity of the backface antenna oriented reports had a surveillance file number of "0". This was the result of the beacon reports not correlating with the surveillance file. This problem occurred predominately on the en route sensor back-face antenna when nonunique correlation conditions existed. This problem appears to be a software anomaly in software release 7.2 and is under investigation.

SUMMARY OF RESULTS

PHASE I.

The surveillance characteristics of the Mode S terminal and en route configured sensors operating with an effective receive beam width of 2.4° and software release 6.3 are summarized as follows:

1. Pd of the Mode S targets was greater than 98 percent for both sensors.

2. Pd for ATCRBS targets was greater than 98 percent for both sensors at an R/R of 0.93 or greater. The Pd of both sensors decreased approximately 15 percent for an R/R of 0.7 and maximum fruit rate of 8 replies per sweep.

3. The ID reliability for Mode S targets was 100 percent for both the terminal and en route configured sensors under all conditions tested.

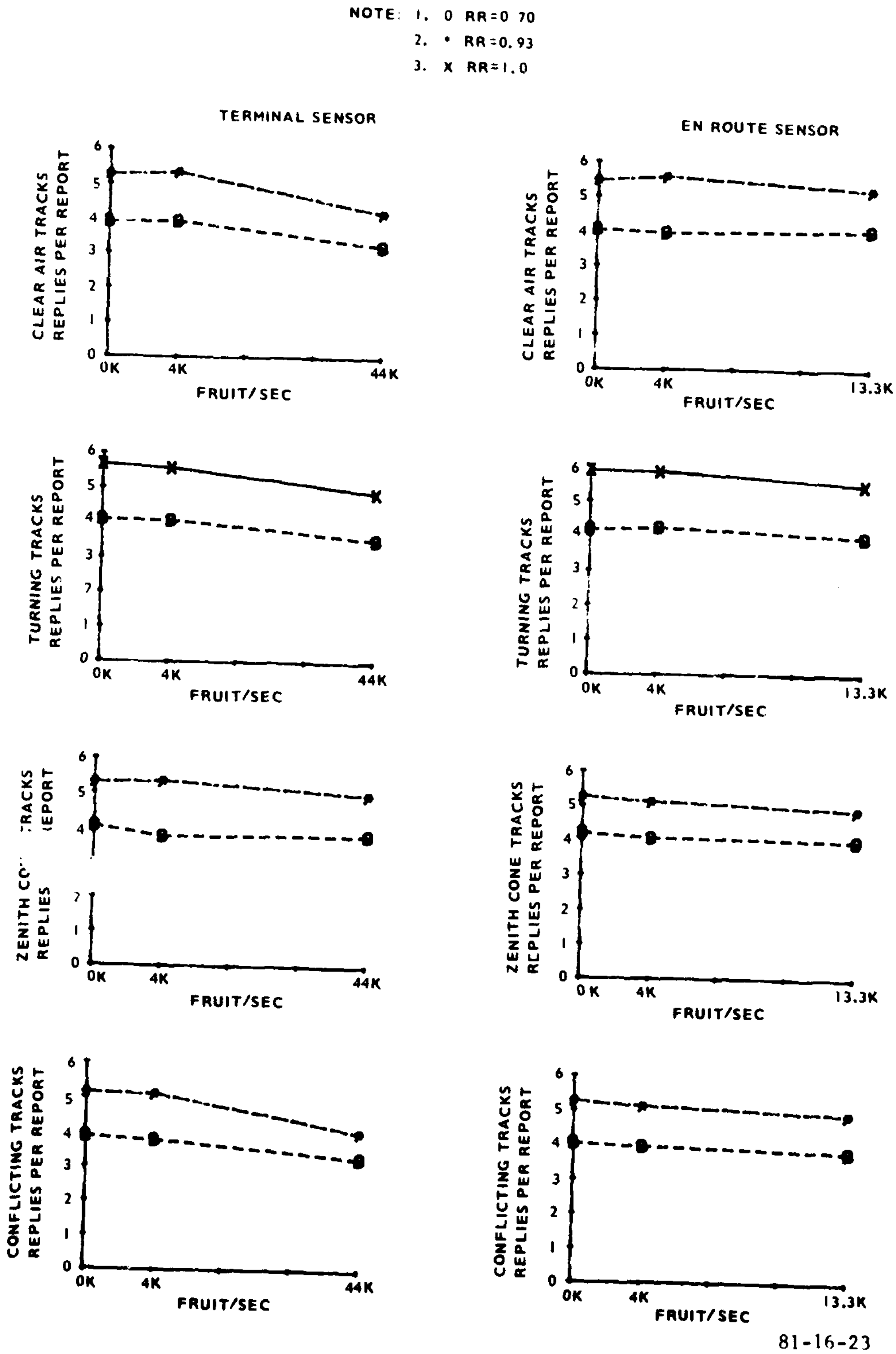

FIGURE 23. REPLIES PER REPORT (ATCRBS) TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE BEAM WIDTH 3.4°

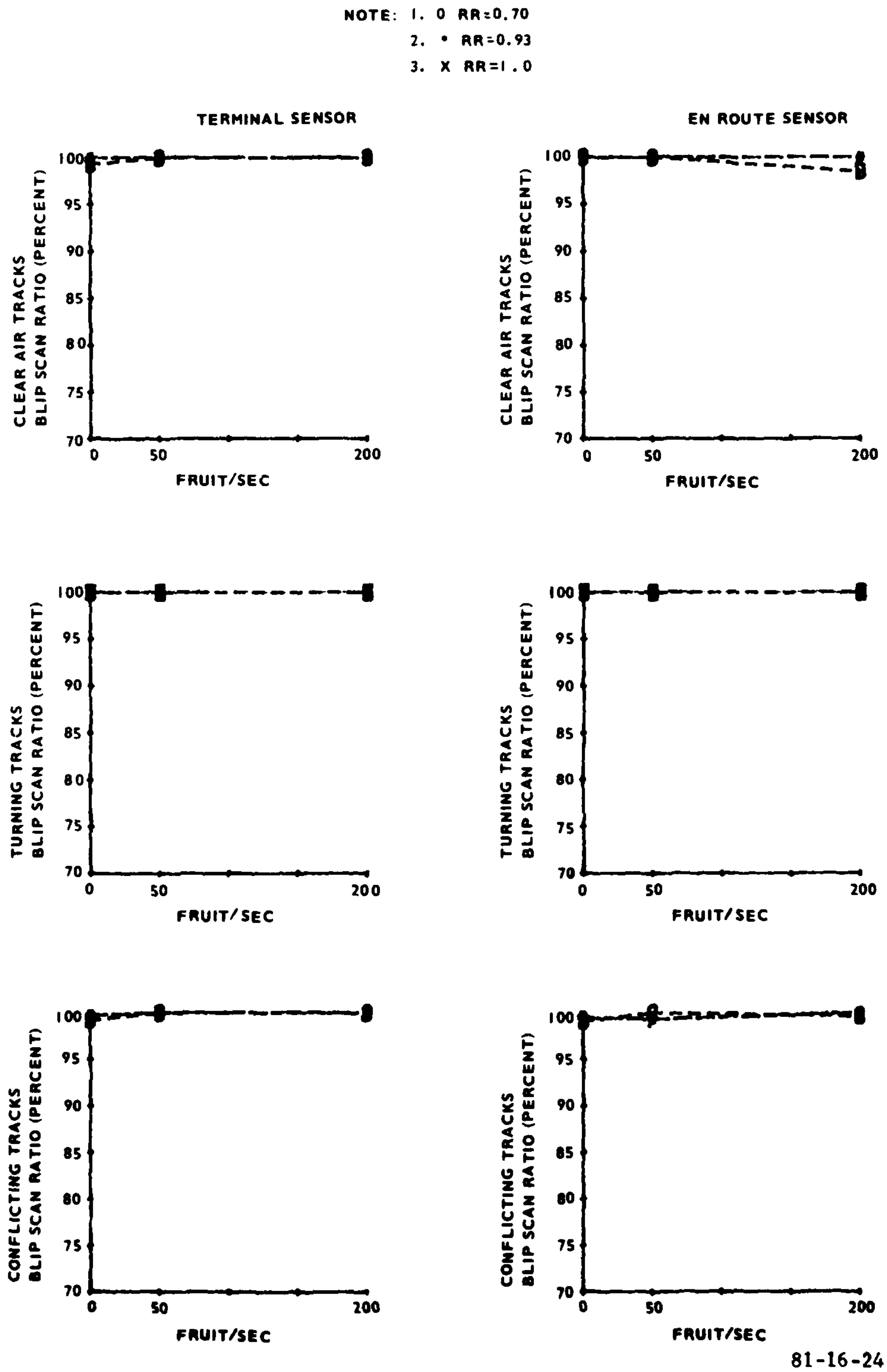

FIGURE 24. BLIP SCAN RATIO (MODE S) TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE BEAM WIDTH 3.4°

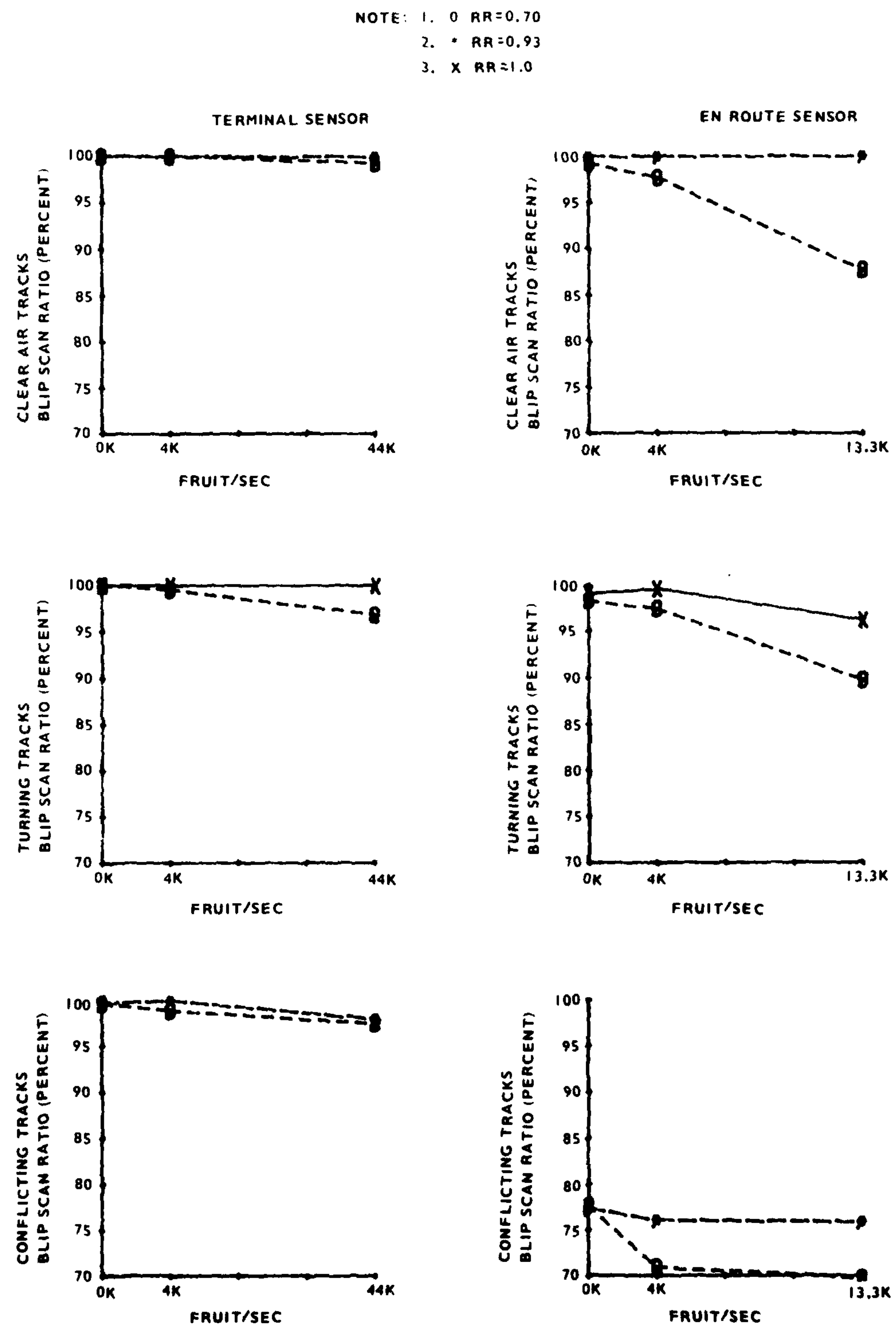

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FIGURE 25. BLIP SCAN RATIO (ATCRBS) TERMINAL VERSUS EN ROUTE SENSOR, EFFECTIVE BEAM WIDTH 3.4°

4. ATCRBS Mode 3/A code reliability was greater than 97 percent for both sensors at all test conditions.

5. Altitude reliability of Mode S targets was 100 percent for both sensors.

6. Altitude reliability of ATCRBS targets for both sensors agreed to within 3 percent for an R/R of 0.93 or greater. Clear air and turning tracks demonstrated an altitude reliability of 96 to 100 percent, while conflicting tracks ranged from 86 to 89 percent. For an R/R of 0.7 and maximum fruit rate of 8 per sweep, the en route sensor was about 3 to 6 percent greater in altitude code reliability than the terminal sensor. The percentage change was due to the greater fruit density at the terminal sensor.

7. Interrogation rates for Mode S targets averaged 1.2 at the terminal sensor and 1.4 at the en route sensor for an R/R of 0.93 or greater. The higher interrogation rate at the en route sensor was due to a release 6.3 software problem. The interrogation rates increased approximately 30 percent for both sensors when the R/R was decreased to 0.70.

8. Replies per report for ATCRBS targets averaged 3.8 at the terminal sensor and 3.7 at the en route sensor for an R/R of 0.93 or greater. When an R/R of 0.7 was tested, the replies per report decreased to an average of 2.8 for both sensors.

9. The b/s for Mode S targets was greater than 99 percent for both sensors.

10. The b/s for ATCRBS targets was greater than 98 percent for both sensors at an R/R of 0.93 or greater, with one exception. Due to a software association/correlation lockout problem, a new track was improperly initiated on one of the en route sensor conflict tracks. This resulted in a reduction of the b/s ratio. Removing this one track from the b/s statistics produced a b/s ratio greater than 99 percent.

PHASE II.

The performance of the Mode S terminal and en route sensors operating with an effective receive beam width of 3.4° and software release 7.2 are summarized as follows.

1. The Pd of Mode S targets at both sensors was 99 percent or greater.

2. The Pd of ATCRBS targets for both sensors was greater than 98 percent at an R/R of 0.93 or greater. The Pd at an R/R of 0.7 increased approximately 7 percent when employing the wide beam width as compared to a beam width of 2.4°. Both sensors indicate about a 10 percent decrease in Pd as fruit increased to the maximum value tested of 8 replies per sweep.

3. Mode S ID reliability remained at 100 percent for both sensors under all conditions tested.

4. ATCRBS Mode 3/A code reliability decreased at both sensors as the fruit rate increased when using software release 7.2. The cause of this reduction was due to a change in software release 7.2, which disseminated data to correlating users

prior to report-to-track correlation in an effort to improve sensor capacity. The data reduction programs utilized the data disseminated to correlating users for analysis. Analysis on data disseminated to noncorrelating users indicated the ATCRBS Mode 3/A code reliability was equal to that obtained with software release 6.3.

5. The Mode 3A code reliability at maximum fruit decreases more at the terminal sensor than at the en route sensor due to a greater fruit density at the terminal sensor.

6. Altitude code reliability of Mode S targets remained at 100 percent for both sensors under all conditions tested.

7. Altitude code reliability of ATCRBS targets improved from 3 to 10 percent at both sensors as a result of increased effective receive beam width allowing more opportunity for high confidence altitude replies. At high fruit rates the altitude reliability of the terminal sensor is about 15 percent less than the en route sensor due to a greater fruit density.

8. Interrogation rates for Mode S targets decreased at both sensors as effective receive beam width was increased.

9. Replies per report for ATCRBS targets increased from an average of 3.8 to 5.2 at both sensors due to increasing the effective receive beam width from 2.4° to 3.4°. The replies per report at a maximum fruit rate of 8 replies per sweep at the terminal sensor is lower than that of the en route sensor due to a greater fruit density.

10. The b/s of Mode S targets was greater than 99 percent for both sensors under all conditions tested.

11. The b/s for ATCRBS targets was improved about 2 percent for the terminal sensor as beam width increased at an R/R of 0.7 independent of fruit rates and aircraft tracks. The en route sensor performance highly correlated with the terminal sensor, except at high fruit rates and for conflicting aircraft tracks. The decrease in the en route sensor b/s was due to a software problem in the front-to-back face antenna association/correlation functions.

CONCLUSIONS

The following conclusions are based upon the results of the surveillance simulation tests performed on a Mode S (formerly Discrete Address Beacon System (DABS)) terminal and an en route configured sensor, each operating with:

1. The 5-foot Air Traffic Control Radar Beacon System (ATCRBS) antenna.

2. Effective receive beam width of 2.4° and software release 6.3.

3. Effective receive beam width of 3.4° and software release 7.2.

It is concluded that:

1. The percent detection (Pd), indentifier (ID) code reliability, altitude code reliability, and blip scan (b/s) ratio of Mode S targets at both sensors were unaffected by the change in effective receive beam width.

2. The interrogation rate for Mode S targets decreased at both sensors as the beam width was increased.

3. The Pd of ATCRBS targets at both sensors decreased as a function of reduced R/R and increasing fruit rate. A slight improvement in Pd of ATCRBS targets was noted at both sensors as the effective receive beam width was increased.

4. The ATCRBS Mode 3/A code reliability decreased at both sensors as the fruit rate increased using software release 7.2 and an effective receive beam width of 3.4°. This descrease was only apparent from data being disseminated to correlating users. Examination of data disseminated to noncorrelating users indicated a Mode 3/A code reliability in agreement with that achieved using software release 6.3 and effective receive beam width of 2.4°. The reduced Mode 3/A code reliability of data being disseminated to correlating users was due to a software change implemented in software release 7.2 which disseminated data to correlating users prior to report-to-track correlation.

5. The altitude code reliability of ATCRBS targets was improved at both sensors by increasing the effective receive beam width.

6. The Mode 3/A code reliability, altitude code reliability, and replies per report performance at maximum ATCRBS fruit rates of 8 replies per sweep are better at the en route than at the terminal sensor due to a lower fruit density.

7. The replies per report for ATCRBS targets increased at both sensors for increased effective receive beam width. At maximum ATCRBS fruit rates of 8 replies per sweep, the replies per report are lower at the terminal sensor than the en route sensor due to differences in the fruit density.

8. The b/s ratio for ATCRBS targets was not significantly affected at either sensor by increasing effective receive beam width. However, an en route sensor software problem for front-to-back face antenna association/correlation function decreased the b/s ratio at high fruit rates and conflicting tracks.

RECOMMENDATIONS

The following recommendations are based upon the results of the surveillance simulation tests performed on a Mode S (formerly Discrete Address Beacon System (DABS))terminal and an en route configured sensor, each operating with:

1. The 5-foot Air Traffic Control Radar Beacon System (ATCRBS) antenna.

2. Effective receive beam width of 2.4° and software release 6.3.

3. Effective receive beam width of 3.4° and software release 7.2.

It is recommended that:

1. An effective receive beamwidth of 3.4° be utilized as means of:

   a. Increasing percent detection (Pd) of ATCRBS targets.

   b. Increasing altitude reliability of ATCRBS targets.

   c. Reducing the interrogation rate of Mode S targets.

2. If some form of ground-to-air collision avoidance system is to be implemented, then subsequent software releases correct the en route sensor front-to-back antenna face correlation problems.

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